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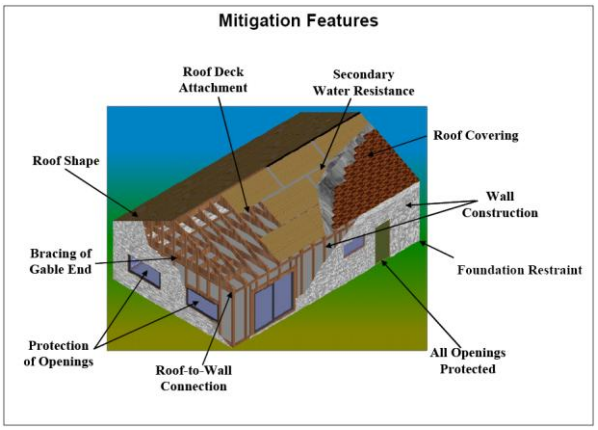
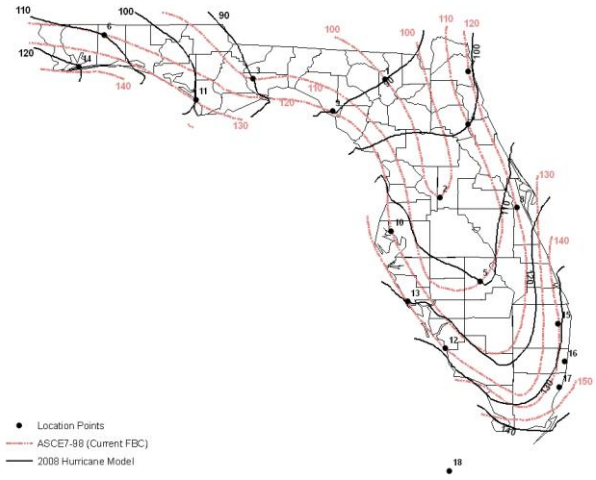
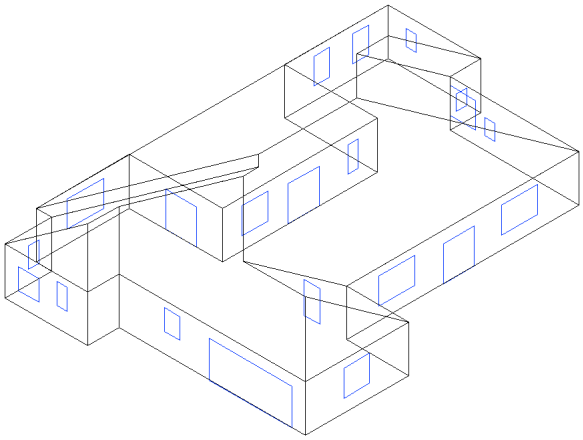
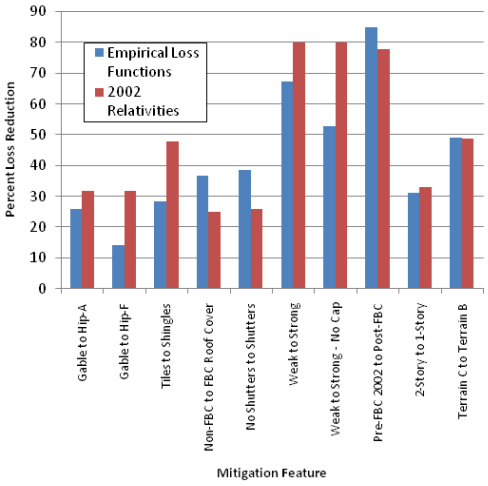
2008 Florida Residential Wind Loss Mitigation Study









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Preface

The Florida Office of Insurance Regulation (OIR) released a Request for Proposal (07/08-12) on November 20, 2007 for a "Residential Wind Loss Mitigation Study". Subsequent to the proposal evaluations, a contract was awarded to Applied Research Associates, Inc. (ARA) on January 17, 2008.

The scope of this project is to evaluate windstorm loss relativities for construction features including, but not limited to, those which enhance roof strength, roof covering performance, roof-to-wall strength, wall-to-floor-to-foundation strength, opening protection, and window, door, and skylight strength. The study includes single family and multi-family homes. A significant element of the scope involves the analysis of damage and loss data from the 2004 and 2005 Florida hurricanes. The analysis and integration of new engineering load and test data have also constituted a major element of the study.

The information contained herein is based on a number of detailed modeling, calculation, and report integration steps. A systematic effort has been made to check and verify the data in this report. If errors are discovered, they will be corrected in future report updates and/or memoranda. ARA makes no representations or warranties regarding possible interpretations regarding the use of this document.

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Executive Summary

A research project has been conducted to estimate the effects of wind-resistive building features in reducing hurricane damage and loss to single family and multi-family residential structures located in the state of Florida. This project is the first attempt to systematically update previously developed loss mitigation relativities (ARA, 2002a and 2002b).

The scope of this project has included residences built prior to the introduction of the Florida Building Code 2001 (pre-FBC era) and residences built in the post-FBC period. In order to reflect wind-resistive design improvements implemented in the FBC, the post-FBC construction period includes two eras: FBC 2001 and FBC 2006 (i.e., the 2006 revisions to the 2004 FBC).

The technical approach used in this study is based on the analysis of individually-modeled buildings at numerous locations in Florida. For post-FBC construction, the buildings were designed to the FBC 2001 and FBC 2006 according to the design wind speed, wind-borne debris region, and FBC definitions of Terrain Exposure. Each building has been modeled with a specific set of wind resistive features. There are two broad classes of buildings: single family houses and multi-family (5 or more units) residences. The multi-family residences include three groups, based primarily on building height and roof deck material: Group I (less than 60 feet tall with wood roof decks), Group II (less than 60 feet tall with non-wood roof decks), and Group III (more than 60 feet tall).

The loss mitigation features considered in this project are summarized in the following table:

Single family and Group I Multi-family		*Groups II and III Multi-family*	
2002 Features	***Features Added in 2008***	***2002 Features***	***Features Added in 2008***
1. Terrain 2. Roof Shape 3. FBC, Non-FBC Roof Cover 4. Secondary Water Resistance 5. Roof-to-Wall Connection 6. Roof Deck Material/Attachment 7. Opening Protection 8. Gable End Bracing 9. Wall Construction 10. Wall-to-Foundation Restraint	1. Number of Stories 2. Roof Cover Material 3. Roof Slope 4. Soffit Construction 5. Vinyl Siding 6. Window/Door Water Leak Potential 7. FBC Roof Cover Age 8. Group I Only: Parapets and Rooftop Equipment 9. Minimal Condition Requirements	1. Terrain 2. Design Building Code 3. Design Windspeed 4. FBC, Non-FBC Roof Cover 5. Opening Protection 6. Roof Deck Material 7. Secondary Water Resistance	1. Parapets 2. Rooftop Equipment 3. Window/Door Water Leak Potential 4. FBC Roof Cover Age 5. Minimal Condition Requirements

The new features included in this study reflect knowledge gained from damage surveys and engineering data analysis. The minimal condition requirements, added in 2008, include conditions for roof cover, roof deck, and windows/doors. These components should be in a reasonably good and acceptable condition for the building to receive any wind mitigation rate differentials. Definitions and requirements for wind mitigation features are summarized in Appendix A.

A major task in this project included the analysis of insurance and damage data from the 2004 and 2005 Florida hurricanes and engineering data from laboratory tests and wind tunnel experiments. The key conclusions from the analysis of the 2004 and 2005 insurance loss data include:

1. Post-FBC (permitted after March 1, 2002) homes have losses 75 to 90% lower than pre-FBC homes.
2. Two-story homes, on average, have 31% higher losses than one-story homes.
3. Gable roof houses have 14 to 28% higher losses than hip roof houses.
4. Tile roof houses have 28% higher losses than shingle roof covers.
5. Opening protection on windows significantly reduces losses (39%).
6. Houses located in Terrain B (suburban) have significantly reduced losses (49%) over houses located in Terrain C (open).

7. Houses with several mitigation features have notably reduced losses (53- 67%) over houses with no mitigation features.

Given the limitations of these data, the insurance loss results should be viewed as simply rough empirical measures. However, the trends are significant and provide some confidence in the magnitude of the modeled loss reductions predicted in 2002 and updated herein.

The results of the wind mitigation analysis are presented in the form of "loss relativity" tables. These tables are based on computations of average annual loss and measure the loss reduction effectiveness of all possible combinations of the modeled wind mitigation features. The tables provide a convenient way to "look-up" the effectiveness of wind mitigation features on any building. The loss relativities were developed for 2% deductible. The loss relativities can be used directly to compute insurance rate differentials on the wind premium. The rate differentials only apply to the portion of the wind premium associated with the dwelling, its contents, and loss of use (not any attached or detached structures). Attached and detached structures are not built to the same standards as the dwelling and must be excluded from rate differentials; the study also assumes that insurance coverage for attached and detached structures includes a separate deductible that does not accrue to the dwelling deductible.

Significant reductions in loss (lower loss relativities) are achieved on all building types when they have the appropriate wind mitigation construction techniques. While these reductions are similar in magnitude to the results obtained in the 2002 studies, the additional construction features included in this study result in a broader range of loss reduction relativities, when measured from the "weakest" building. The loss reductions for the strongest pre-FBC era buildings and all post-FBC constructed buildings, as measured from the "weakest" modeled building, are generally greater than 80% for single family and Group I multi-family residences and on the order of about 55% to 80% for Group II and III buildings. When measured from a "typical" pre-FBC strength building, loss reductions for post-FBC buildings range from 10 to 70%, with a typical reduction of about 50%. These loss reduction differences are based on hundreds of thousands of simulated years of hurricanes and therefore include the full statistical range of weak to maximum intensity hurricanes. One would not expect to see these magnitudes of loss reductions in weak or moderate intensity hurricanes.

A key focus of the loss relativity development has been to capture the ongoing improvements in wind mitigation knowledge and techniques. While the details of the proper interpretation and application of rate differentials contained herein may be viewed by some as overly complex, the procedures reflect both the inherent variations in construction techniques as well as the engineering details embedded in the FBC. Over simplification of the measures of loss reduction (e.g., by simplifying the results to smaller tables with fewer features) also seems counter to the state's investments in improving the building code as well as in promoting public awareness of mitigation techniques. Eliminating features for the purpose of achieving simplicity would also result in lost opportunities for both awareness and mitigation of those features (including code-plus construction). We note that a 1% reduction in average annual residential loss in Florida would amount to an annual statewide loss reduction savings of about $50 million in 2008 dollars. Each 1% loss reduction that we can wring out of new construction (through FBC improvements) and existing construction (through mitigation) will result in long-term exponential reductions in statewide losses.

These results do not include recent research on terrain effects and wind-borne debris, which has been funded by the state over a three-year period. That research was conducted under a separate project and was not completed in time to meet the schedule requirements of this project. However, that work is now ready for integration and should be incorporated immediately into an update of the loss relativities. This integration will address several shortcomings of this work and is also essential to producing a consistent set of wind loss mitigation measures usable in a statewide uniform grading scale. We recommend that this integration and update proceed immediately prior to implementation of these loss relativities as wind mitigation rate differentials.

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1 Introduction

1.1 Objective

The objective of this project is to evaluate windstorm loss relativities for construction features including, but not limited to, those which enhance roof strength, roof covering performance, roof-to-wall strength, wall-to-floor-to-foundation strength, opening protection, and window, door, and skylight strength.

Two previous studies were performed in 2002 to quantify wind loss reduction for wind mitigation construction features. "Development of Loss Relativities for Wind Resistive Features of Residential Structures" focused on single-family homes (ARA, 2002a). "Development of Loss Relativities for Wind Resistive Features for Residential Buildings with Five or More Units" addressed condominium and renter occupancies in buildings with five or more units (ARA, 2002b).

This document addresses both single-family and multi-family residences. It provides data and information on the estimated reduction in loss for wind-resistive building features for residential property insurance. It provides a technical basis for actuarially reasonable discounts, credits, or other rate differentials, for construction techniques demonstrated to reduce the amount of loss in a windstorm.

1.2 Scope

The scope of this study includes, as a minimum, the wind resistive features called out in the Florida statutes, namely:

1. Enhanced Roof Strength
    a. Roof deck connection to roof framing
    b. Roof deck material and strength
2. Roof Covering Performance
3. Roof-to-Wall Strength
4. Wall-to-Floor-to-Foundation Strength
    a. Wall-to-floor strength
    b. Floor-to-foundation strength
5. Opening Protection
    a. Windows
    b. Doors
    c. Skylights

Additional features are examined in this study. These additional features include features that influence wind losses and features that mitigate wind losses. These features have been identified from hurricane damage surveys, insurance loss data, and engineering data.

The scope is limited to single-family and multi-family residential buildings. Commercial occupancies are not considered.

A major element of the scope of this study is the requirement to consider and analyze the loss data from the 2004 and 2005 Florida hurricanes. These data include both damage survey data and insurance company loss data. The insurance loss data include both policy level loss amounts ($) by coverage type and detailed claim level data. Claim data include detailed item-by-item information on the physical damage to the structure, as well as loss information (i.e., the costs for repair, replacement, contents, attached and detached structures, and loss of use). A major thrust of this project is to analyze as much insurance data as is possible within the project's schedule and budget constraints.

This study uses hurricanes as the windstorm to quantify the loss relativities. Hurricanes dominate the severe wind climate in Florida and, hence, are the primary contributors to windstorm loss costs.[1] This approach is consistent with the FBC design windspeed map, which is based on hurricane winds.

The scope of this project includes residential buildings built prior to the statewide adoption of the Florida Building Code (FBC) in March 2002 (the 2001 FBC edition) and residential buildings built after the statewide adoption of the FBC. These eras are referred to as "pre-FBC" and "post-FBC," respectively.

The mitigation features must be practically verifiable so insurers can be reasonably confident a particular residential building qualifies for the rate differentials. Hence, the scope of consideration for wind loss mitigation construction features must be limited by the capability to inexpensively verify.

The scope of work also implies that the measures of construction feature effectiveness in reducing windstorm loss (i.e., "the loss relativities") are to be converted to "insurance rate differentials". Hence, this study also outlines the simple conversion step from "wind mitigation loss relativities" into "insurance rate differentials."

This study is intended to provide a complete update to the wind loss relativity studies published in 2002 (ARA, 2002a and 2002b). The work is based on new and standalone analyses, new data, and improved technical modeling capabilities. The results herein are therefore not constrained to "match or replicate" the 2002 loss relativity results.

1.3 Review of 2002 Studies

The 2002 Loss Relativity Studies (ARA, 2002a and 2002b) were the first-ever comprehensive approach to develop a modern wind loss classification system and systematically quantify wind mitigation loss relativities for single- and multi-family residences. The basic approach used in the 2002 studies was to estimate how loss costs change with wind resistive fixtures and construction techniques by using engineering analysis and repair/replacement cost methods for individually-modeled buildings. Three-dimensional models of buildings were developed with and without specific wind-resistive fixtures. These buildings were then analyzed for hurricane damage and loss using load and resistances modeling techniques, consistent with modern engineering design methods. Monte Carlo Simulation was used to analyze thousands of hurricanes striking each modeled building at specific locations in Florida. Analysis of this simulation data provided the statistics to quantify losses and the effectiveness of specific combinations of wind mitigation features.

The 2002 loss relativity reports documented a number of assumptions and limitations. For the single family residences, one of the major qualifications included the fact that only one story houses were modeled. This limitation is addressed in this study by treating both one- and two-story houses. The 2002 single family study treated only shingle type roof covers. Both shingle and tile roof covers are treated herein. New research on roof slope has been completed and is incorporated in this research. Soffits are also included as a new factor. Wood panel shutter impact tests were conducted in 2003-4 and these results have been considered in this work. For the multifamily residences, rooftop equipment and parapet height on flat roof structures are introduced as new factors. Related research on wind-borne debris, residential building spacing, and terrain effects on wind loads has progressed since the 2002 studies, but this research was not fully completed in time to be included in this work. There are many other possible factors that could be considered separately (such as skylight, porches, built-in garages, metal roofs, tree fall, etc.). For

[1] Thunderstorm winds, tornadoes, and the occasional extra-tropical cyclone can also produce high winds in the state (see Section 2.4.3). However, hurricanes have the greatest potential for widespread catastrophic damage and are therefore used herein as the wind hazard for the development of the wind loss mitigation relativities. In general, wind mitigation against hurricane winds is also effective in reducing losses for these other windstorms.

now, these factors are assumed to be built into the overall loss estimations through the statistical relationships in the damage-to-loss model.

1.4 Building Features that Influence Hurricane Damage and Loss

This section includes materials from the 2002 studies with updates. Single family residential features are discussed in Section 1.4.1 and multi-family features are discussed in Section 1.4.2.

1.4.1 Single-Family Residences

For many years, engineers have focused on the structural frame and load-path issues in designing buildings for wind loads. However, beginning in the 1970's, engineers began to document the importance of the building envelope (roof deck and covering, roof-to-wall connection, windows, doors, etc.) performance in influencing the resulting financial loss experienced by buildings in windstorms. In many storms, the building frame performed adequately, but the windows and/or doors failed, often due to impact by wind-borne debris. Roof covering was almost always damaged, resulting in water penetration into the building, particularly for hurricanes.

Damage and the ensuing losses to residential buildings were found to be governed by the performance of the building envelope, including many non-engineered components, such as roof covering, windows and doors, roof sheathing, garage doors, etc. The failure of soffits (usually vinyl or aluminum) can lead to water entering the attic space as well as internal pressurization of the attic space. The key structural frame connection for most failures was the roof-to-wall connection. Foundation failures and frame failures, other than the roof-to-wall frame connection, were found to be extremely rare for site-built houses, except in intense tornadoes. In most cases, if damage to the frame or foundation did occur, it was preceded by the failure of other components.

These observations stand in sharp contrast to earthquake induced damage to buildings, which is governed primarily by the building foundation and building frame performance.

Figure 1-1 illustrates the key building envelope features for site-built houses that affect hurricane damage and loss. Figure 1-2 illustrates how the loads increase dramatically once the building envelope fails. Failure of a small opening can lead to large internal pressures. These pressures act outward on the walls and roof on the leeward and back side of the building and can result in a doubling of the loads on the building envelope. This phenomenon is why the failure of a window often produces a progression of failures in the roof deck, whole roof, or other openings that quickly lead to large insurance losses.

Roof Covering. Roof covering performance (Figure 1-3) is important since partial loss of the covering allows hurricane rain water to enter the building. Hurricanes are tropical storms and rain is always an integral part of the storm. Once water enters the building, the losses begin to increase dramatically. Drywall, electrical, floor coverings, and contents are easily damaged and the losses mount up quickly. Review of insurance claim folders supports these observations.

Another major problem with roof coverings is the fact that failure of the covering produces debris that is accelerated by the wind and becomes airborne "missiles" capable of easily damaging unprotected glazing. Figure 1-4 shows the typical case of roof covering failure from a house that produced impacts and multiple penetrations of the neighboring house. The cost of replacing the damaged roof cover varies with the roof covers type. Tiles roofs are typically cost 2 to 5 times more than shingle roofs (depending on the tile type), thus in cases where the only damage to a house involves the replacement of the entire roof cover, the insurers costs are clearly much higher in the case of equally damage tile vs. shingle homes.

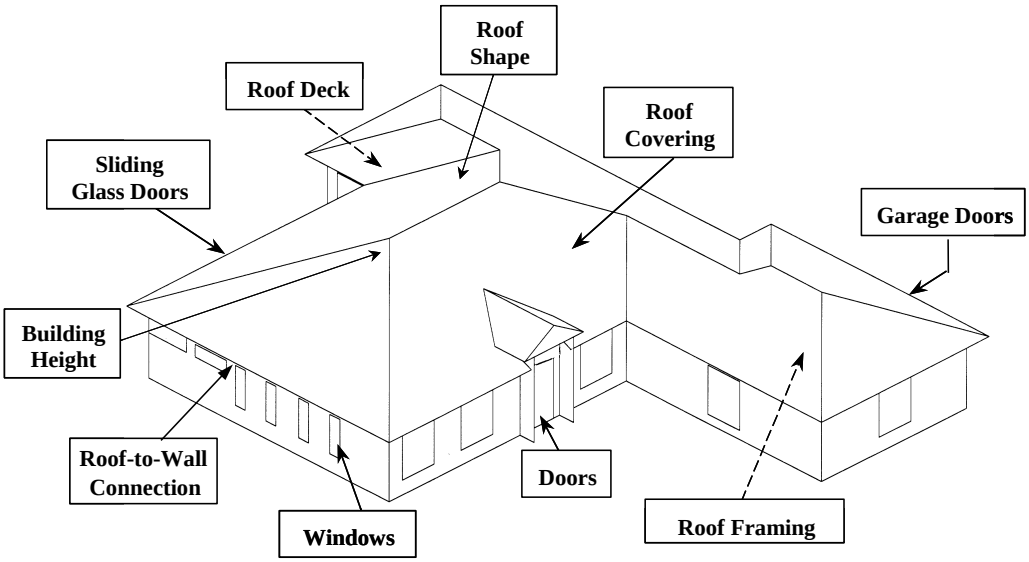


Figure 1-1. Building Envelope Features that Control Damage and Loss.

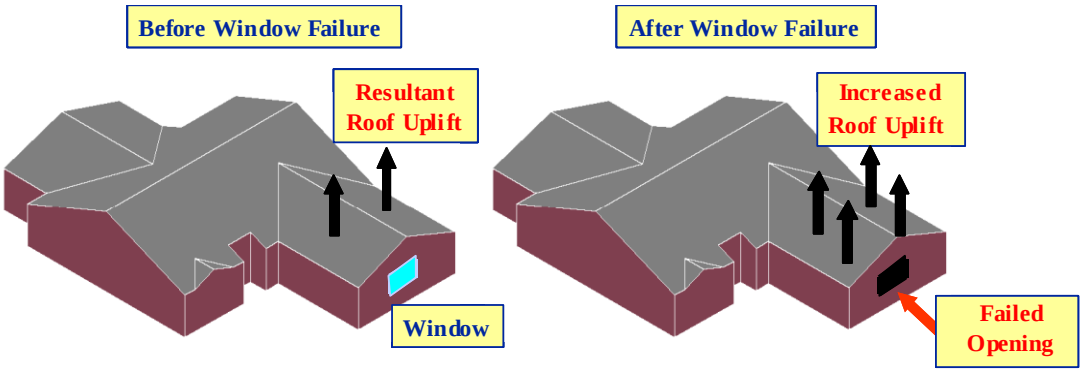


Figure 1-2. Protection of Wall Envelope Reduces Chances of Internal Pressurization.



Figure 1-3. Loss of Roof Covering Leads to Interior Water Damage.

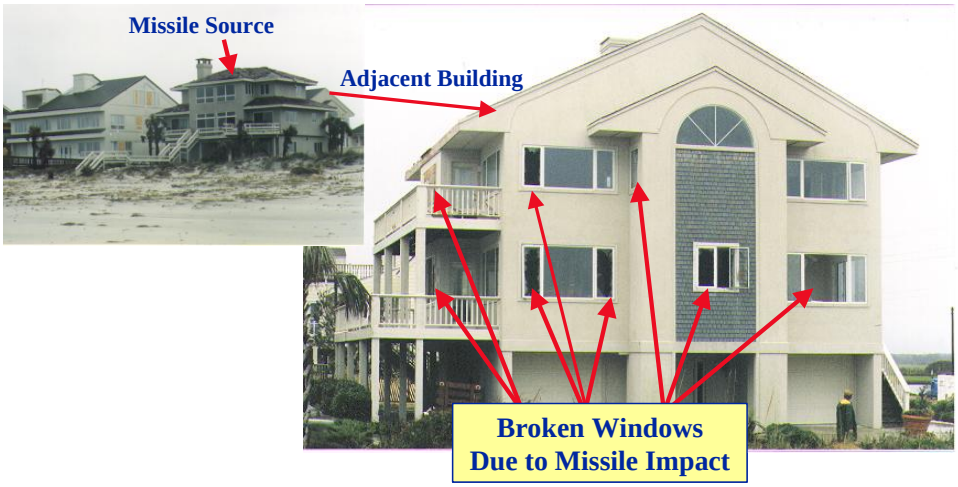


Figure 1-4. Loss of Roof Covering Produces Wind-Borne Debris.

Roof Deck. Roof deck attachment during a hurricane is critical to the survival of the building (Figure 1-5). Once a building looses one or more pieces of roof deck, the losses increase exponentially due to the vast amount of water that enters the building. Field observations and insurance claim folders indicate that the house quickly becomes a major loss once the roof deck begins to fail in a hurricane. In other words, even if the walls are intact and the roof trusses do not fail, loss of roof deck and a few windows typically leads to losses greater than 50% of the insured value.



Figure 1-5. Roof Deck Performance, Hurricane Andrew.

Roof-to-Wall Connection. One of the most important connections in a house is the roof-to-wall connection. The critical loads on the roof are negative (suction) pressures that produce uplift forces on the roof. Toe-nailed roof-to-wall connections, a relatively common building practice in the past, are especially vulnerable to failure (Figure 1-6). Properly installed hurricane straps that connect the roof truss to the wall frame generally provide for adequate resistance to uplift roof failures. Houses with gable ends are also vulnerable to gable end wall failures (Figure 1-7), although these failures are not, on average, large contributors to loss.

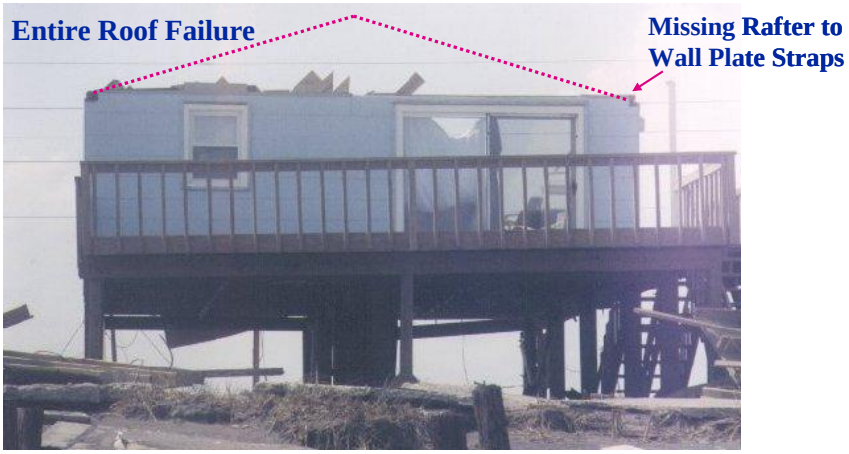


Figure 1-6. Roof Truss/Rafter to Wall Connection.



Figure 1-7. Gable End Failure, Hurricane Andrew.

Roof Shape. The shape of the roof influences the aerodynamic loads experienced by the roof covering, roof deck, roof framing and connections. Figure 1-8 illustrates gable and hip houses at Navarre Beach (on the same street), following Hurricane Erin in 1995. Gables, on average, do not perform as well as hips due to roof shape aerodynamics and the lack of roof-to-wall connections on all 4 sides of the house. Roof slope has an effect on the building aerodynamics. Low slope roofs (around 4:12) are very common in Florida, but the maximum uplift pressures near the gable ends decrease with increasing roof slope indicating that information on roof slope might be important in assessing loss potential.

Openings. Openings include windows, doors, skylights, garage doors, etc. As illustrated in Figure 1-9, openings can fail in various ways. The most common is from impact by wind-borne debris. Once the building envelope is breached, the internal pressures build up and increase the likelihood of roof failures. Garage doors (Figure 1-10) and other doors and skylights are also vulnerable to failure. Any glazed opening, unless it is protected or is impact-resistant, is highly vulnerable to failure from flying debris.



(a) Gable – 1



(b) Gable - 2



(c) Hip - 1



(d) Hip - 2

Figure 1-8. Performance of Same Street Hip and Gable Houses at Navarre Beach during Hurricane Erin.

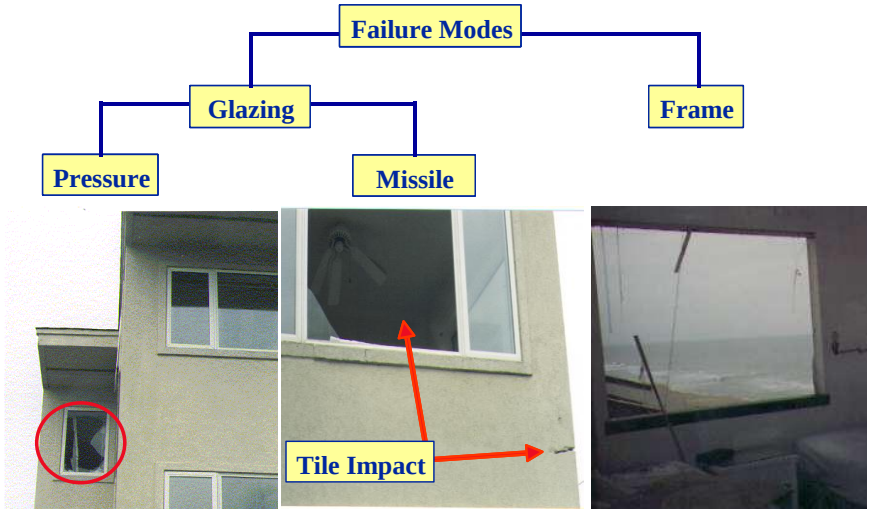


Figure 1-9. Failure Modes for Windows and Openings.



Figure 1-10. Garage Door Performance.

The fact that windows and doors have movable parts and do not seal perfectly when closed makes them vulnerable to leak during a hurricane. Rain water can be forced through these gaps as a result of the pressure differences across the building envelope. The resulting water leaks through window and door systems contribute to interior losses.

Soffits. Failure of soffits (usually being sucked down from the eaves) often leads to the water getting into the attic space. After the soffits fail, when the wind direction changes so that positive pressures are experienced on the wall beneath the soffits and the soffit space itself, then rain water is forced up into the attic space. This rain water soaks the insulation and can cause the drywall ceilings to collapse onto the floor and furnishings beneath. Figure 1-11 presents examples of failed soffits that occurred during Hurricane Charley.

Foundation. Wall-to-floor-to-foundation failures are rare for site-built buildings. The most vulnerable houses are low-value buildings that sit atop concrete blocks (Figure 1-12) and have no uplift or lateral restraint. Houses built on stem walls or slabs on grade generally have significant resistance to uplift and lateral forces. They are much more likely to fail in one of the other modes described above. Gravity loads and minimal overturning/sliding resistance is more than adequate to resistance foundation failure of most site-built houses. For houses on piers, bolted or strapped connections designed to carry the loads into the piers generally perform adequately. Foundation failures of site-built houses in hurricanes are almost always caused by storm surge and not wind.



Figure 1-11. Failed Vinyl Soffits in Hurricane Charley.

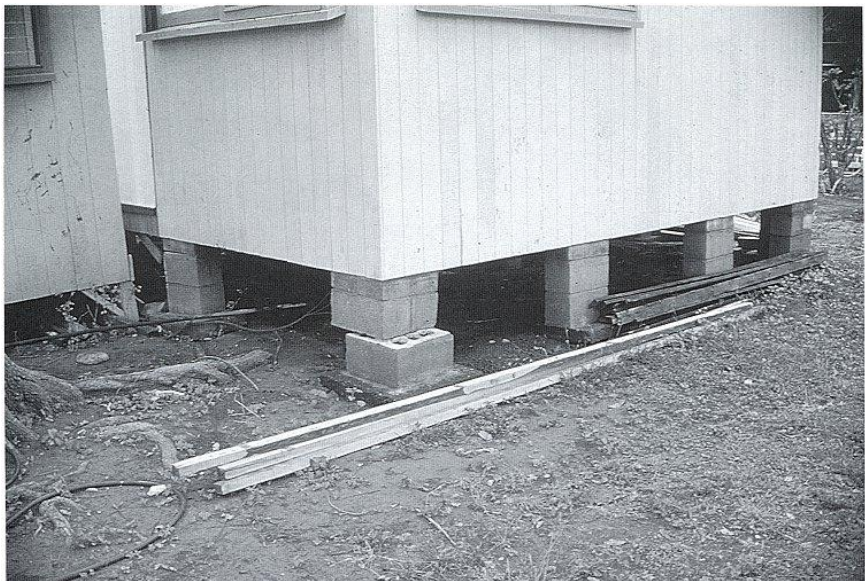


Figure 1-12. Sliding Block Foundation in Hurricane Iniki.

Terrain Features. The effects of terrain (surface roughness) strongly influence the near-ground windspeeds and wind loading environment on buildings. Generally recognized terrain categories include open (Exposure C) and suburban (Exposure B). Two potentially significant extensions to the treatment of terrain are treed terrain and Exposure D terrain (winds blowing from the ocean). In treed terrain, the trees significantly reduce windspeeds compared to a typical open terrain. In the Exposure D, the windspeeds are greater than those in open terrain.

The terrain exposure for a building has a significant impact on the effectiveness of wind loss mitigation features. Terrain is both a building code consideration and an important loss mitigation consideration.

Treed terrain reduces the windspeeds near the ground and the resulting wind loads acting on the buildings and the direct wind damage. Trees also have the potential to fail during wind storms and damage buildings and attached structures.

Figure 1-13 is an aerial view of treed terrain in the Panhandle area following Hurricane Ivan. The trees extend into and around the subdivisions and there are small patches of open terrain in the golf course areas. The red dots are blown-down trees. Analysis of insurance claim data for Ivan indicated that the losses in these treed areas were about ½ that of the losses for homes directly on the coast. Figure 1-14 shows ground level views of treed terrain with residential buildings. The effect of trees includes both the beneficial effects of reducing windspeeds on lowrise buildings and the harmful effects of the risk of property damage and personal injury from tree fall on residences. On average, trees reduce losses, but there are cases in every hurricane where large trees fall and hit small buildings, sometime with deadly results. Additional research is needed to determine the practicality of protecting homes from catastrophic tree fall damage, including strengthening the structure at the eaves sufficiently to stop reasonably large trees from slicing through the structure. In treed terrain, this type of mitigation is expected to more effective than investing in wind pressure related mitigation, since the windspeeds are dramatically reduced below the tree canopy (see Figure 3-45). This research should be completed and integrated into the wind loss mitigation loss relativities as soon as practical, since many residential regions in the northern half of Florida are located in treed terrain.

PenWest Area

PB1 Area



Figure 1-13. Treed Terrain and Tree Fall in Hurricane Ivan.



Figure 1-14. Trees Reduce Windloads but Introduce Tree Fall Risk.

For Exposure D locations, such as on barrier islands, hurricane losses are influenced by additional factors such as:

1. Salt water intrusion into the buildings, producing more damage than produced by rainwater entering the building
2. Increased damaged caused by limited access back to the island after the storm, preventing the owner from initiating temporary repairs to prevent subsequent damage and loss
3. Generally increased loss of use cost due to restricted access to barrier islands
4. Longer periods of time without power (thus preventing rapid drying out of the building)

Due to time constraints, quantitative assessments of treed and Exposure D terrains were not included in this project.

1.4.2 Multi-Family Residences

The performance of a multi-family residential building in a hurricane is also governed by the performance of the building envelope. Most of the potential failure models that are observed in single-family residences are also observed in the multi-family residences, particularly in the case of the smaller wood frame and masonry multi-unit residential buildings. Flat roof buildings are more common in multi-family construction, and thus additional modes of failure unique to flat roofs play a more important role in multi-family construction as compared to single-family construction. The ability to place HVAC units on the roofs of flat roof buildings adds a frequently observed failure mode that is not seen in the case of sloped roof buildings. Figure 1-15 shows some of the key building components responsible for producing loss in hurricanes in a typical multi-family residence. The follow sections present examples of some of the more commonly observed failure modes on multi-family units.

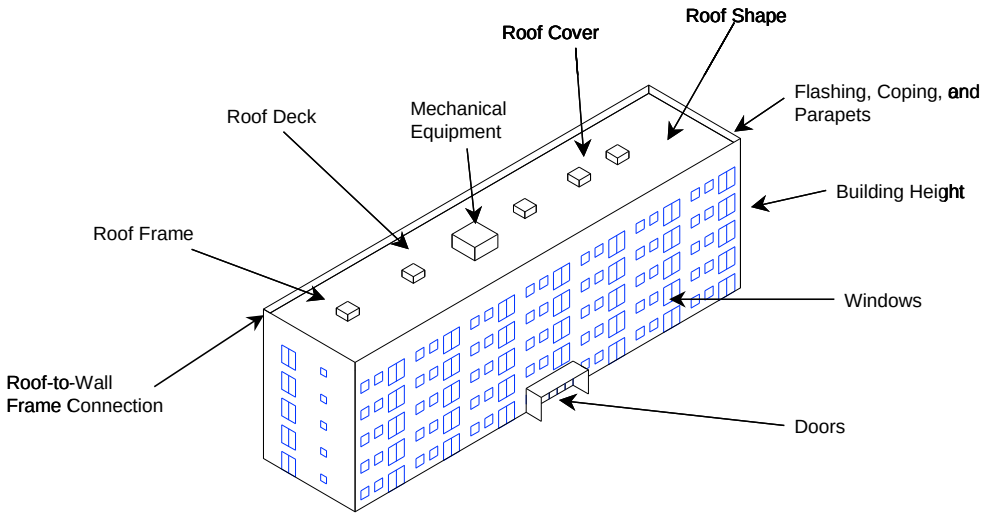


Figure 1-15. Features that Control Hurricane Damage and Loss for Buildings with 5 or More Units.

Roof Cover and Roof Shape. The performance of the roof cover in a hurricane is a key to the performance of large buildings. Once the roof cover fails, water begins to enter the building and damages interior drywall, electrical and mechanical systems, floor covering, and contents. For flat roof shapes, which are common for multi-story buildings, the performance of the roof cover is critical due to the potential for significant water leakage into the building.

The performance of shingles and tiles on low-rise multi-family buildings is similar to that seen for single-family buildings. Figure 1-16 illustrates partial loss of roof cover on a condominium building in Hurricane Erin.



Figure 1-16. Shingle Damage to Condominium Building from Hurricane Erin.

A large number of multi-family dwellings are constructed with flat roofs with a single ply membrane, modified bitumen, or built-up roof. Figure 1-17 show some examples of failed single ply membrane roofs. In addition to being attached to the roof with mechanical attachments or being adhered to the roof, membranes can be held to the roof using ballast. The ballast is usually gravel or paving stones. Ballasted roofs make up a relatively small percent of the population of flat roofs.



Figure 1-17. Examples of Single Ply Membrane Failures on Multi-Family Housing Units.

Figure 1-18 shows an example of the interior damage caused by the loss of a single ply membrane roof. In most cases, the failure of a built-up roof, a single ply membrane roof or a modified bitumen roof initiates when the flashing at the edges of the building fails.



Figure 1-18. Interior Damage to Condominium Caused by Water from Failed Roof Membrane.

Figure 1-19 shows an example of the failed flashing at the edge of a modified bitumen roof. Failure of single ply membrane roofs can also be initiated by tearing of the membrane caused by the impact of flying debris and by tearing caused by rooftop equipment becoming dislodged in high winds. On buildings with single ply membrane roofs, built-up roofs, or modified bitumen roofs, once the initial failure begins, a progressive failure generally follows, with the roof cover peeling away from the roof deck. This progressive failure mechanism often results in large areas of the roof deck being exposed to the rain.



Figure 1-19. Example of Edge Flashing Failure on a Modified Bitumen Roof.

Performance of Roof Deck. As in single-family construction, the performance of the roof deck is critical to the overall performance of the entire building in a hurricane. Once a portion of the roof deck fails, significant quantities of water begin to enter the building causing rapid and extensive damage to the interior of the building and its contents. Figure 1-20 shows examples of roof sheathing damage to multi-family housing units.

Rooftop Equipment. Flat-roofed buildings often have air conditioning and other equipment on the roof deck. The tie-down connections and water proofing details around this equipment are important to the roof cover and roof deck performance (see Figure 1-21). Figure 1-22 illustrates the failure of poorly attached air conditioning (AC) units on a condominium building. When rooftop equipment fails, depending on the type of equipment, the equipment can either leave a large opening beneath its original location or, more frequently, perforate the roof membrane when it rolls, tips, or slides from its original location. Once the roof membrane is perforated, rain water enters the building and losses escalate rapidly.



Figure 1-20. Examples of Roof Sheathing Failures in Multi-family Housing Units.



Figure 1-21. Multi-Level Flat Roof with Numerous Equipment and Architectural Frame Penetrations.



Figure 1-22. Example of Failed Rooftop AC Units on High Rise Condominium Tower.

Roof-to-Wall Connections. The failure of roof-to-wall connections results in enormous damage to a building, in most cases causing a loss that approaches the full insured value of the building and its contents. In the case of wood roofs, the construction characteristics of multi-family buildings are often the same as those used in single-family construction. Such characteristics may include the use of weak (toe-nail) connections for the roof truss to wall. Figure 1-23 shows an example of a roof-wall connection failure on a two-story condominium unit that occurred during hurricane Erin in 1995.



Figure 1-23. Examples of Roof-Wall Connection Failure.

For buildings with steel roofs, the roof is usually constructed using open web steel joists, with a welded connection to the wall frame. Open web steel joist roof systems generally fail under wind loads either through buckling of the lower chord of the joist or through an uplift failure of the welded connection attaching the joist to the wall.

Opening Failures. Opening failures in multi-family buildings result from a combination of breakage from wind-borne debris impacts as well as pressure-induced failures, either inward or outward. Once a window has failed, damage to the interior of the building is caused through the introduction of wind and water into the building. Figure 1-24 shows windows on the corners of a high rise condominium tower that failed due to the action of wind pressures during Hurricane Opal in 1995. Figure 1-25 presents examples of windows that failed due to wind pressures on a three-story condominium building. Sliding glass door failures are also common (see Figure 1-26). Improved designs of the sliding glass door framing can dramatically improve performance (see Figure 1-27) for both wind loads and water intrusion.



Figure 1-24. Window Failures on High Rise Condominium Tower.



Figure 1-25. Additional Examples of Window Failures in a Multi-Family Building.



Figure 1-26. Sliding Glass Door Failure in Condominium Building.



Figure 1-27. Step-Over Installation of Sliding Glass Door and Strengthened Frame.

Foundation Failures. In the case of multi-family dwellings, foundation failures, for practical purposes can be ignored, since few, if any large buildings, have been built without adequate restraints. Foundation failures that have occurred in past hurricanes have almost always been associated with the action of storm surge and waves and not wind loads. However, the connections for buildings on piers need to be adequately designed and periodically inspected for corrosion.

Building Envelope. The building envelope governs the losses for condominium and renter occupancies. These types of buildings, particularly flat roof structures, often exhibit a higher sensitivity to envelope performance than do single-family structures. The multi-unit occupancies of condominium or tenant buildings mean that failure of the roof can affect losses in many units that have experienced no exterior window or door failures.

As with single-family residences, the loads on the building increase dramatically once the envelope fails. The failure of openings on the top floor can lead to significant increases in the loads acting on the underside of the roof, increasing the chance of roof deck failure.

Soffit. Soffit failures may occur on one-, two- and three-story multi-family residences. These failures can produce internal pressurization and/or the water intrusion into the attic space. Figure 1-28 presents an example of failure soffits on a one-story multi-family unit.



Figure 1-28. Failed Soffit on One-Story Multi-Family Housing Unit (Hurricane Charley)

Window Leakage. As in the case of single-family residences, windows and doors are vulnerable to water intrusions. Current standards require that these components prevent water penetration for pressures up to only 15% of the design pressure. Leakage through windows and sliding glass doors remains a major vulnerability for large, multi-family buildings.

1.5 Organization of the Report

Section 2 reviews the technical approach and methodology. It includes a review of the Florida Building Code, hurricane wind modeling, locations, building models, simulation approach, and insurance assumptions.

Section 3 summarizes new data analysis, including, insurance company damage and loss data, field survey data, and new engineering research data. A significant amount of insurance data has been analyzed to determine the effectiveness of wind mitigation factors and to understand non-mitigation factors and their contribution to insured loss. Model updates are summarized in Section 3.6.

Sections 4 and 5 present the loss relativities for single-family and multi-family residences. Each section has separate tables for pre-FBC and post-FBC construction.

Section 6 discusses the implementation of loss relativities with respect to insurance rate differentials. Step-by-step procedures for determining the loss relativities and rate differentials are presented and illustrated with examples.

The summary and recommendations are presented in Section 7. Section 8 includes a reference bibliography.

Appendix A discusses wind mitigation features and summarizes the definitions of the features considered in this study. Appendix B illustrates the hurricane modeling data used in the insurance loss data analysis Section 3. Wireframe views of the modeled buildings are included in Appendix C. Example FBC design calculations are given in Appendix D and example results for modeled buildings are illustrated in Appendix E.

2 Methodology

2.1 Technical Approach

The fundamental approach used in the 2002 loss relativity studies (ARA, 2002a, 2002b) was to analyze individually-modeled buildings at numerous locations in Florida. Each building was modeled with a specific set of wind-resistive features. By evaluating all possible combinations of the basic wind mitigation features, tables were produced that showed the relative difference in loss costs for buildings with different construction features. For new construction to the 2001 FBC, model buildings were designed to the FBC in the various wind zones in the state. Simplified tables of loss relativities were produced for these new code buildings such that year built provided a basic input to determine the wind loss relativity. ARA's HURLOSS methodology, which is based on engineering models of individual buildings, was used to analyze each modeled building for damage and loss.

The technical approach for this 2008 loss relativity update is fundamentally the same as the approach used in 2002. However, the scope of this study is naturally broader than the 2002 scope in that we now have significant amounts of new information. This new information includes engineering research on building loads and resistances, additional hurricane windfield measurements, laboratory tests, full-scale testing, damage surveys and, perhaps most importantly, insurance loss data from recent Florida hurricanes. This information is used to improve both the modeling and the validation of the loss relativities.

The basic methodology for this study is summarized in Figure 2-1. Five main sources of new data are factored into this study:

1. Lab and Full-Scale Test Data
2. Field Damage Surveys from Florida Hurricanes
3. Florida Building Code Updates
4. Insurance Loss Data
5. Hurricane Wind Model Updates

Highlights of each of these areas are also shown in Figure 2-1. For example, a significant amount of new information exists on roof pressure coefficients for hip and gable shaped roofs. This research was funded by the Florida Building Commission and is included in the wind mitigation analysis. Another example listed in Figure 2-1 is the exterior structure survey performed under the OIR study on "Insurability of Attached and Detached Structures." These data provide a basis for understanding the effects of attached structures on Coverage A losses for both mitigated and unmitigated single-family residence. The insurance loss data analysis will be a centerpiece of this study in terms of assessing the effectiveness of wind loss mitigation features and also for updating the modeling of economic loss given a damaged structure. A significant update to the hurricane wind modeling has occurred since 2002, and the new model will be used in this study.

The new data and analysis from Items 1-4 feed into updated damage and loss models. The new hurricane model research has already been completed under other projects. The new hurricane wind model (Item 5) has been used to produce simulated hurricanes for multiple Florida locations.

The production of the loss relativities involves the selection of the Florida locations, insurance parameters, and model buildings. The Florida locations are selected to ensure that all wind zones are included and that there is good spatial coverage of the state. The insurance parameters are selected to represent the most common situations, recognizing that the many combinations of deductibles and coverage limits are beyond the scope of this study. Loss costs will be produced for each modeled building at each simulated location. Sensitivity analyses are performed to help select the final wind mitigation features for both the primary loss relativity tables and the secondary factors.

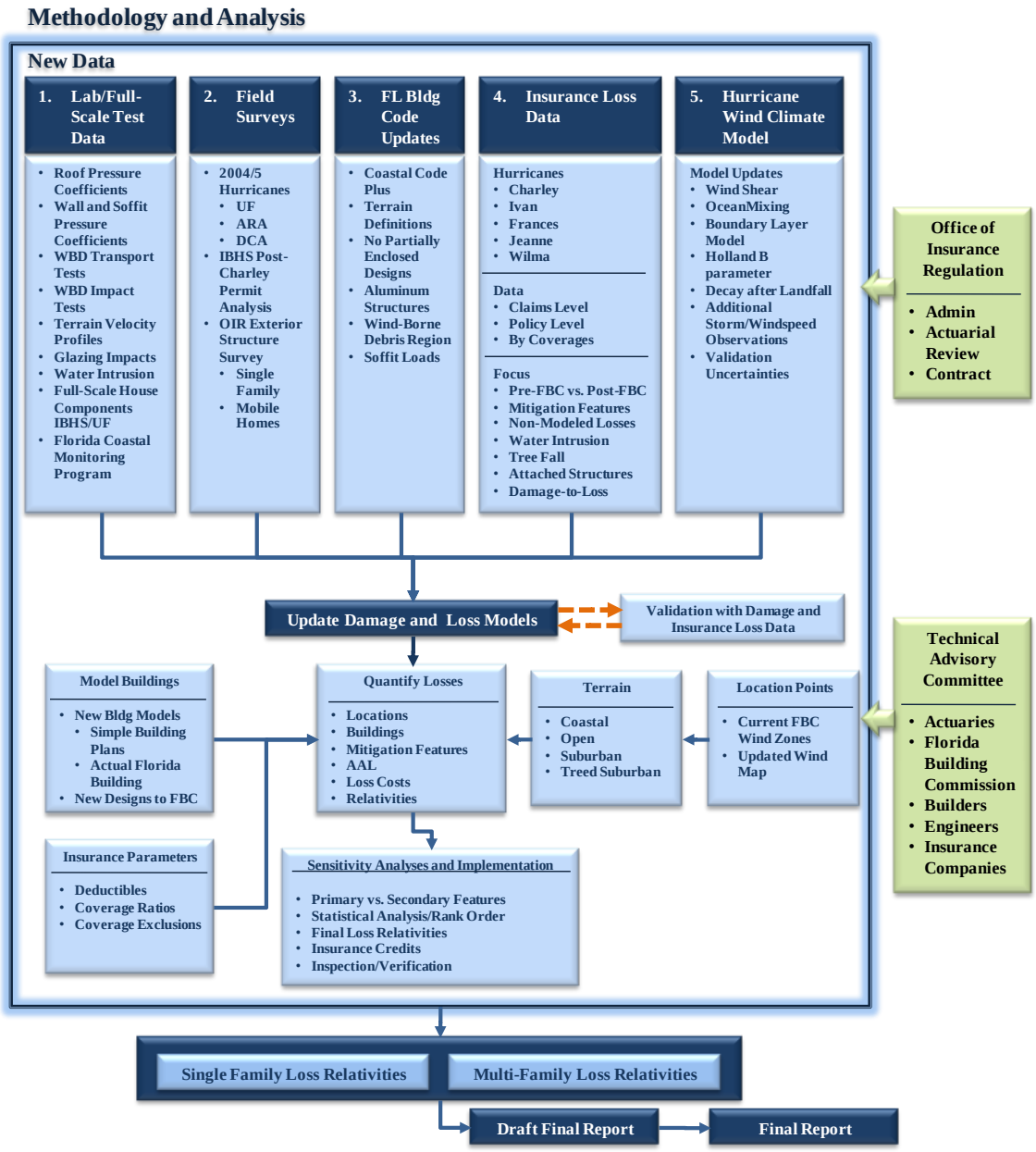


Figure 2-1. Overview of Loss Mitigation Study Methodology.

The last step involves the conversion of loss relativities into insurance credits for single-family and multi-family residences. In 2002, the OIR used the loss relativity tables to normalize the relativities according to the "weakest" building (highest relativity). Following that approach, every building that has at least one mitigation feature over the weakest building receives a mitigation credit.

2.1.1 Background on Loss Relativities

The term "loss cost" is an insurance term that measures the long term statistical average of loss for a particular building and a particular hazard over a one year period. The hurricane loss costs for a single building is the long-term statistical average of annual covered hurricane losses divided by the building replacement value. Loss costs are the mathematical expected value of losses (normalized by

building value) over many years at a particular location. For a particular building type, the loss costs will vary from location to location as a result of variations in both the hurricane hazard risk and terrain (aerodynamic roughness). Loss costs are a fundamental measure used by insurance companies to establish insurance rates.

Hurricane and wind hazard loss costs are dependent on the building's location, basic construction features, and wind mitigation construction features. Weak buildings have high losses relative to building value (high loss costs) and strong buildings have low losses relative to building value (low loss costs).

Loss relativities are produced by normalizing loss costs for each building type by the loss costs of an arbitrarily selected reference building. Figure 2-2 illustrates how loss relativities can be produced for three different buildings. The average annual losses for hurricane wind hazards are first estimated for each building, considering the location, terrain, basic construction features and wind mitigation features. The average annual losses are normalized to produce loss costs (per thousand dollars of building value). Normalizing the loss costs by the weakest building produces a relativity of one for the weakest building and relativities less than one for the stronger buildings. In this example, House 2 has a loss relativity that is 58% of House 1 and is therefore more resistant to wind damage than House 1. In summary, loss relativities provide a single non-dimensional measure of a building's ability to withstand damage/economic loss from hurricane wind effects relative to some reference building at the same location.

3 Houses with Different Wind Mitigation Features	Value	Avg Annual Loss (AAL, $)	(AAL / Value)	Loss Costs (per $1000)	Loss Relativity
1. 	$300,000	$1,800	0.006	$6.00	1.00
2. 	$200,000	$700	0.0035	$3.50	0.58
3. 	$100,000	$400	0.004	$4.00	0.67

Figure 2-2. Example of Loss Cost Relativities for Three Different Houses.

2.1.2 Interpretation of Loss Relativities

There is much confusion and lack of understanding of loss costs and the fact that they represent long-term statistical averages, based on mathematical expectation. Long term simulations are required to achieve stability in the statistical means of expected annual loss. The use of a single event or even a few events of insurance losses requires significant analysis to extract useful validating data. The analysis approach of analyzing the data in strata by peak gust windspeeds provides a useful approach to understanding insurance loss data. The windspeed zones are developed from modeled windspeeds calibrated to land and marine anemometer measurements and dropsondes for that hurricane. The insurance data are analyzed by these strata and losses are assessed. The differences in building

construction features are more meaningful for the high wind zones that are near or exceed the design windspeeds for that location.

Most hurricanes do not stress the building envelope of even old code buildings. Since building envelope failures control the largest portion of hurricane loss costs, losses from modest hurricanes across building features will not, in general, match the loss cost relativities. In high wind events (generally with winds greater than about 120 mph), the dramatic effects of mitigation can be seen and large differences in loss result. Many old code structures will begin to come apart as winds exceed 120 and 130 mph. Another confounding factor is that in a single event, the strong winds for a location generally occur over an azimuth range of about 90 to 120 degrees. The orientation of the building, particularly its roof shape and orientation relative to the strong winds will have an enormous influence on the loads on the building in that event. For example, quartering winds on a gable roof will produce loads that are 2-3 times higher than winds normal to the gable roof. Hence, for identical houses in the same neighborhood (but facing different directions), one could have its roof deck fail while its neighbor only loses some shingles. Both buildings experienced essentially the same peak gust windspeeds; but, the actual loads are determined by the roof pressures, which are highly wind-direction dependent. However, over many storms over many years, the wind directions tend to average out (for example, in Miami, the effect of house orientation on loss costs is less than about 5% from worst facing direction to best facing direction) and hence the loss relativities are essentially the same regardless of building orientation.

2.2 Florida Building Code

The State of Florida first mandated statewide building codes during the 1970s, requiring local jurisdictions to adopt one of the model codes. The damage produced by Hurricane Andrew and other disasters in the 1990s revealed fundamental building code weaknesses and also that building code adoption and enforcement was inconsistent throughout the state. The state responded to this situation by reforming the state building construction system with emphasis on uniformity and accountability. The Florida Building Code (FBC) became the state-wide building code effective in March 2002. The single statewide code is developed and maintained by the Florida Building Commission. It has significant wind-resistive design requirements and continues to be updated and improved through a proactive and highly interested group of professionals. The Florida Building Commission and the Florida Department of Community Affairs have funded critical research that is focused on fixing problems in the code and improving design requirements.

The FBC supersedes all local codes and is automatically effective on the date established by state law. The Florida Building Code system requires building code education requirements for all licensees and uniform procedures and quality control in a product approval system.

The FBC is compiled in six volumes: Building, Residential, Plumbing, Mechanical, Fuel Gas, and Existing Building. The National Electrical Code© is adopted by reference. This scope of this project involves wind resistive construction features, which are in the Building Volume. The following sections provide some preliminary discussion on key FBC topics relevant to this study.

2.2.1 Wind Zones and Wind Borne Debris

The FBC follows the ASCE 7 national standard in terms of design windspeeds and the model building codes in terms of wind-borne debris region. Figure 2-3 shows the current design windspeeds and wind-borne debris region for the state. In the Wind-Borne Debris Region (WBDR), all glazed openings must be protected for wind borne debris with approved protective devices (shutters or impact resistant glazing). The 2001 edition of the FBC allowed an option for partially enclosed designs in the WBDR (outside of the HVHZ) that are not protected with shutters or impact resistant glass. This provision meant that a designer in the WBDR had the option of designing the structure as an enclosed building (with protection

of glazed openings) or as a partially enclosed building (without protection of glazed openings in which the design assumes that wind entering the building adds to the loads on the structure). As of July 1, 2007 (by law and per amendment of the 2004 FBC), the FBC no longer allows for partially enclosed design in the WBDR and all buildings in the WBDR require protection for glazed openings.

The WBDR includes all areas where the basic windspeed is 120 mph or greater and any areas within one mile of the coast where the basic windspeed is 110 mph or greater (shaded area of Figure 2-3). The 2001 FBC included a Panhandle WBDR exception, which included the eastern border of Franklin County to the Florida-Alabama line. In this region, WBD protection was required only for areas within one mile of the coast. An amendment to the 2004 FBC (effective July 1, 2007) did away with the Panhandle Exception and the WBDR includes all locations in the state with design winds ≥ 120 mph.[2]

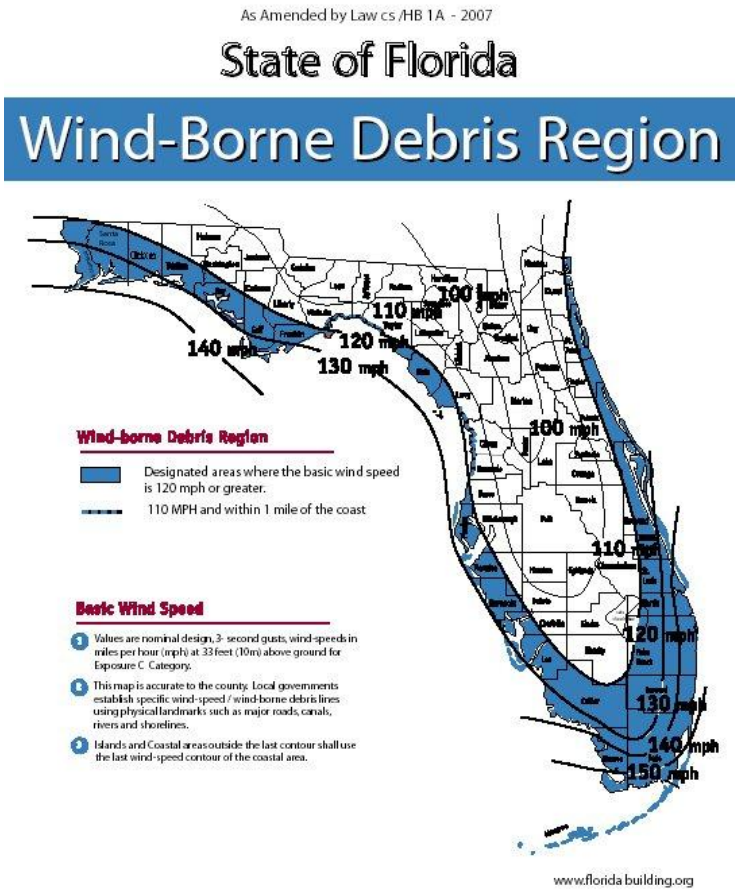


Figure 2-3. Wind Regions in Florida Building Code.

2.2.2 Terrain Exposure

The effect of terrain (i.e., the reduction in windspeed near the ground produced by the frictional effects of buildings and vegetation) has a significant impact on windspeeds and, hence, wind-induced damage and loss. The magnitude of the reduction of the windspeed at any height is a function of the size and density of the obstructions (buildings, trees, etc.) on the ground, as well as the fetch (distance) the wind has blown over a given terrain. Terrain also affects the turbulence intensity, velocity profiles, and wind-borne debris environment that act on the building.

Terrain is a fundamental parameter in the design of structures for wind loads. Terrain is recognized in most national and international wind loading codes through the use of simplified terrain categories defined, for example, as open terrain, suburban terrain, urban terrain, etc. When designing a building, a design engineer must first determine what terrain a building is going to be built in, and design the building to resist the associated wind loads. In ASCE-7, the U.S. national wind loading standard, there is a significant increase in the design loads associated with designing a building located in open terrain (Exposure C) compared to the case of a building designed for suburban terrain conditions (Exposure B). For example, the design loads for the cladding (windows, doors, roof sheathing, etc.) of a 15 ft tall building located in Exposure C are 21% more than those for a building located in Exposure B, and for a 25 foot tall building the difference in the design loads is 34%. The true effect of terrain is in most cases

[2] Also, effective in February 2007, Florida law required local governments to use the ASCE 7 WBDR for Panhandle immediately, before the 2004 FBC was amended.

greater than that indicated in the building codes which tend to conservatively underestimate the reduction in wind load that is experienced for most buildings located in suburban terrain.

Terrain remains one of the more difficult parameters to specify for an individual building because it involves assessments of the site well beyond the buildings and land immediately surrounding the structure. Terrain remains a difficult issue for engineers, designers, building code practitioners to interpret and for the Florida Building Commission to codify. Determining the terrain for a building requires knowledge of the site and surroundings for the full 360 degrees of azimuth outward for distances up to one mile, in some cases. Further, the definitions of exposure are subject to different interpretations by knowledgeable practitioners.

Building Codes and Terrain. Notwithstanding the differences in building code eras and definitions of terrain, the effect of terrain has a dramatic effect on wind loads on a building. As noted above, terrain is generally referred to as exposure category in building codes and load standards. The upwind exposure category is based on ground surface roughness that is determined from vegetation and constructed facilities. Surface roughness or aerodynamic roughness produces a reduction in windspeed near the ground from the frictional effects of buildings and vegetation.

ASCE 7 currently recognizes three surface roughness or terrain exposure categories:

1. ***Surface Roughness B:*** Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.
2. ***Surface Roughness C:*** Open terrain with scattered obstructions having heights generally less than 30 ft.
3. ***Surface Roughness D:*** Flat, unobstructed areas and water surfaces outside hurricane prone regions.

The terrain exposure category is defined according to the distances over which various surface roughness conditions prevail for each wind direction considered. The ground surface roughness is generally measured in terms of roughness length, z_o. Each surface roughness category corresponds to a range of z_o. ASCE 7 also allows interpolation between terrain exposure categories.

The terrain definitions in the FBC 2001 used the exposure category (terrain) definitions of ASCE-7 with a few important exceptions (see FBC Sections 1606.1.8 and 1619.3):

1. Exposure C (open terrain with scattered obstructions) applies to:
   a. All locations in HVHZ (Miami-Dade and Broward Counties)
   b. Barrier islands as defined per s.161.55(5), Florida Statues, as the land area from the seasonal high water line to a line 5000 ft landward from the coastal construction control line
   c. All other areas within 1,500 ft of the coastal construction control line, or within 1,500 ft of the mean high tide line, whichever is less
2. Exposure B (urban, suburban, and wooded areas) practically applied to all other locations in Florida by virtue of the current definitions for Exposures A and D.

The FBC has modified the above terrain definitions since 2001 (see FBC 2004) and further changes are underway. In general, Florida is moving toward terrain definitions more in line with ASCE 7. In ASCE 7, Exposure C is the default exposure rather than the FBC 2001 definitions, which made Exposure B the default exposure. It is possible that Exposure D will be brought back into the ASCE-7 wind loading standard for hurricane-prone regions when the design windspeeds are updated for the 2010 edition. As Exposure D is brought back into ASCE 7, it will also likely be included in the Florida Building Code at about the same time. Data reported in Powell, Vickery, and Reinhold (2003) and Vickery, et al. (2008a) support the use of Exposure D in hurricane prone regions. This new information

suggests that Terrain Category D should be considered in this study. In addition to the wind load issues associated with Exposure D, the wind-borne sand and salt spray environment typical of Exposure D coastal locations may also warrant a separate terrain category for loss mitigation relativities.

Figure 2-4 illustrates terrain transition from the ocean inland, using the ASCE 7 definitions of surface roughness. These terrain transitions reflect the fact that the wind flow is moving from a large open body of water onto land and the transition, in terms of effect on small buildings, takes place over relatively short distances. Buildings that face the open body of water or are within a few hundred feet of the water experience a more severe wind loading environment compared to those that are located further inland.

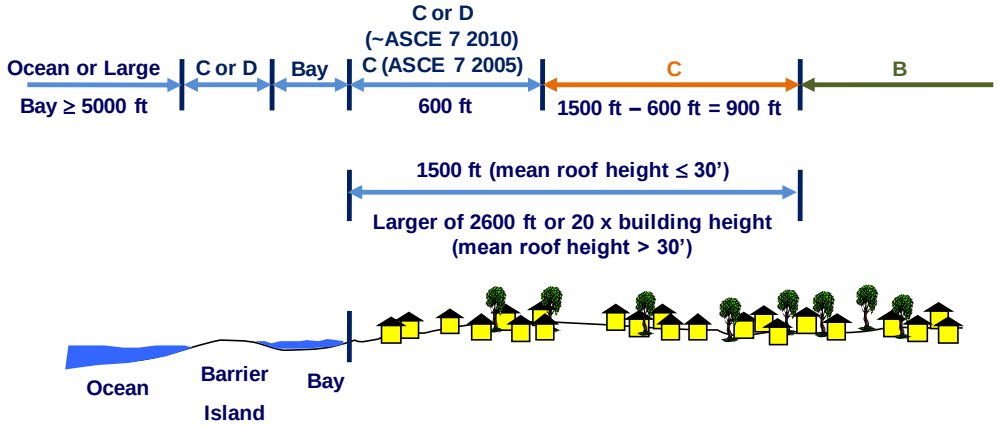


Figure 2-4. Illustrative Terrain Transition and Roughness Categories for Ocean Exposures.

There are also potential differences in building code terrain, building design terrain, and actual terrain. As noted above, the definitions of building code terrain have changed over time and hence building code terrain may be dependent on building code eras. In some of the old building codes, different terrains were not recognized for single-family residences. Also, there may be differences in the building code terrain and the terrain used by the designer of the building. Finally, actual terrain is what is important in assessing wind loss mitigation. If a building has been designed for a more severe terrain than it is actually in (for example, inland HVHZ locations in actual Terrain B designed for Terrain C), then the building's wind mitigation is, of course, greater than that of a building designed for Terrain C that is actually in Terrain C. These factors further complicate the treatment of terrain in wind loss mitigation analysis.

Role of Terrain in Assessing Wind Loss Mitigation Effectiveness. In the 2002 loss relatively studies, we used separate loss relativity tables for terrain and each terrain table was self-normalized. The difficulty of dealing with terrain in determining wind loss mitigation relativities centers on how to define terrain for loss mitigation implementation. While insurance company windstorm rates are generally thought of as being location-dependent and not terrain-dependent, in most locations the effect of terrain may be inherently reflected into the rates. With this line of thinking, the insurance application of wind loss mitigation relativities could be based on the predominate terrain for each rating territory. On the other hand, if an insurance company treats location and terrain separately in their rates, then that insurance company would use the appropriate loss relativity table for the terrain representative of the building location. This approach recognizes that within a rating territory, such as a county, there are almost always multiple terrain categories and these different terrains will have a dramatic influence on the risk of loss for individual buildings in that territory.

Treed Terrain. Field damage surveys and insurance loss and claims data show the significant impact of wooded terrain on residential losses. Houses and small buildings in tall tree environments,

where the trees are typically 2-3 times the height of the building, experience dramatically reduced wind loads. On the other hand, tree fall on dwellings, fences, and outbuildings, introduces increased risk of loss in treed terrains. Modeling, coupled with insurance claim data, is needed to quantify these trade-offs to determine the net effect of treed terrain on loss relativities of small residential buildings.

Under separate research funding, recent wind tunnel tests examining the effects of trees on the variation of windspeeds with height near the ground and the effect of trees on wind loads provide additional information that will be used to assess the impact of a rougher terrain on loss costs. Figure 2-5 shows the variation of the mean windspeed (left plot) and the turbulence intensity (or gustiness), defined as the standard deviation of the windspeed divided by the mean windspeed (right plot) plotted for various different tree densities. The reduction in the mean windspeed is accompanied by an increase in the turbulence, but the two nevertheless combine to reduce the wind loads acting on the building. However, the reduction in the loads on the building cannot be predicted by the reduction in the mean or gust windspeed alone, and so to address this problem, wind tunnel experiments were performed in which the peak exterior pressures acting on the roofs and walls of buildings were measured. Pressure load reduction factors that vary with tree density were developed to account for the reduced wind loads associated with trees, and can be used to estimate the reduction in direct wind damage to small buildings located in treed terrain.

This research, which combines the effects of terrain (including treed terrain) and WBD on single-family residential losses, is near completion. This work should be incorporated into an immediate update to the loss relativities developed herein. The effects will be dramatic for a good portion of the state.

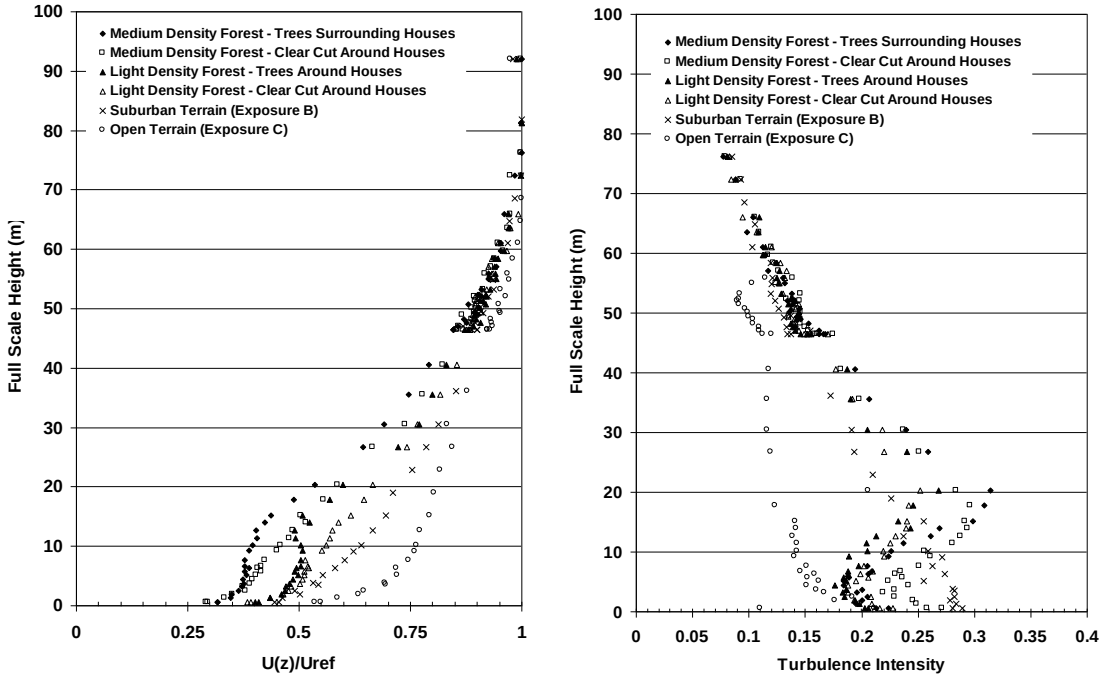


Figure 2-5. Mean Windspeed vs. Height. Left Plot Shows Reduction in Mean Windspeed Near the Ground with Increasing Tree Density. Right Plot Shows Increasing "Gustiness" Near the Ground with Increasing Tree Density.

2.2.3 HVHZ

The FBC identifies a High Velocity Hurricane Zone (HVHZ) for Miami-Dade and Broward Counties (FBC, Sections 202 and 1611ff). This portion of the Florida code comes from the South Florida

Building Code (SFBC). The HVHZ has some important differences with the non-HVHZ areas of the FBC, including:

1. More stringent missile impact test criteria.
2. Requirement that all doors, non-glazed openings, walls, and roof sheathing have missile impact resistance.
3. Did not allow for partially enclosed building design, while FBC allowed partially enclosed designs from 2002 through June 2007.
4. Some restrictions on materials that can be used.
5. Design for Terrain Exposure C conditions.

These requirements make for improved wind resistance for buildings built in the HVHZ. The HVHZ is treated separately in the development of the loss relativities for new construction.

2.2.4 FBC Changes Since 2002

The *Florida Building Code* (*FBC*) has undergone a number of updates since 2001. The key changes that impact the wind resistance of residential buildings are discussed in the following sub-sections. One basic change to the *FBC* since 2001 was the introduction of a separate residential building code in 2004 (*FBC Residential*). The introduction of the residential building code significantly increased the number of windspeed zones for which prescriptive requirements could be used in the design of residential buildings compared to the 2001 *FBC*. In the context of the model buildings used to develop the loss relativities described in this report, the *FBC Residential* applies to all model single family homes and any single-story Group I multi-family buildings.[3]

The following discussion of code changes separately addresses the impact of these changes on wind resistive features, such as roof sheathing attachment, roof cover (shingles, tiles, metal roof, etc.), window protection, etc.

2.2.4.1 Roof Sheathing Attachment

Prior to the introduction of the 2004 *FBC*, prescriptive requirements for roof sheathing attachments in the *FBC* were limited to buildings located in areas with basic windspeeds less than 100 mph, as well as in the High Velocity Hurricane Zones (HVHZ). In the 2004 *FBC Building*, prescriptive requirements were extended to include windspeeds up to 140 mph (Exposure B). In the 2006 *FBC* Supplement (effective December 2006), the prescriptive requirements for roof sheathing in the *FBC Residential* were extended to encompass all windspeed and exposures in the Florida. The residential section of the 2006 *FBC* supplement also called for the use of 8d ring-shank nails in all zones with windspeeds greater than 100 mph, resulting in an approximate doubling of the uplift capacity of roof sheathing (compared to the uplift resistance provided by 8d common nails at the same spacing).

In the 2006 *FBC* Supplement prescriptive requirements of the SSTD 10 Standard for Hurricane Resistant Residential Construction were replaced by the prescriptive requirements of the Institute for Business and Home Safety (IBHS) Guidelines for Hurricane Resistant Residential Construction. For roof sheathing, the biggest impact of this change was the requirement to use ring-shank nails in all areas of the roof rather than just in the edge zones as specified in the SSTD 10 Standard.

The prescriptive requirements of the Florida Concrete and Products Association (FC&PA) and American Forest and Paper Association (AF&PA) standards have not changed since the 2001 edition of

[3] The scope of the *FBC Residential* applies to single family homes not more than three stories and multiple single family dwellings (town houses) not more than three stories above grade in height with a separate means of egress including their accessory structures.

the *FBC*. Because of the requirement to use 8d ring-shank nails in the 2006 *FBC* Supplement, the resistance to uplift provided by the 2006 and later versions of *FBC Residential* code exceed those provided by the Wood Products Promotion Council (WPPC), FC&PA and AF&PA standards, and overall provide a significant increase in the wind resistance of the roof deck for many new houses in Florida.

If roof sheathing connections are designed using the provisions of the *FBC Building* code, then the only difference is in the roof pressure coefficients for components and cladding in ASCE 7-02 vs. ASCE 7-98. The change in the ASCE 7 coefficients increase the wind loads in Edge Zone 3 (corners) but decreases the load in Edge Zone 2.

2.2.4.2 Roof-Wall Connections

As in the case of roof sheathing, the *FBC* allows the use of a number of prescriptive codes for determining the uplift capacity required for roof-wall connections. The prescriptive requirements as given in the *FBC* have changed from engineered in 2001 to all windspeed/exposure combinations beginning with the 2006 edition.

The uplift capacity given in the prescriptive codes depends primarily on the truss span, truss spacing, the wind zone (windspeed) and exposure. Variations in the uplift requirements result from the use of different prescriptive standards (e.g., SSTD 10 vs. AF&PA), the base standard used to define the loads for the calculations, and the choice of approach used to define the loads given a standard. For example, the base code used in the development of the SSTD 10 is the 1997 edition of the Standard Building Code, whereas the AF&PA requirements are based on the wind loads computed using the ASCE 7-98 wind load standard.

There have been no major changes to the uplift requirements in the *FBC* since 2001.

2.2.4.3 Roof Cover

For single family residential construction, the only roof cover types considered herein are asphalt shingles and tiles.

We note that the 2001 FBC required in all Florida windzones ≥ 110 mph that asphalt shingles comply with HVHZ requirements. FBC changes to roof cover requirements include:

- ***Shingles:*** Three different ASTM classes of shingles are now specified (December 2006), with the most significant being the introduction of the Class H shingle, which is an option for regions with design windspeeds of 130 mph or higher. The Class H shingle is tested to meet the requirements for a 150 mph zone as specified by the ASTM D-7158 standard.
- ***Tiles:*** The installation of clay and concrete tiles must now be in accordance with recommendations of FRSA/TRI 07320 Installation Manual, effective November 2005.[4] The tile attachment requirements given in the standard are essentially identical to the manufacturers'

[4] For tiles, the new edition of the *FRSA 07320 Manual* provides for the following:

- Require wood, metal, or other structural support "ridge board" for tile attachment methods 1, 2, and 4A.
- Require *FBC* approved pre-bagged mortar to attach hip and ridge tiles, attachment methods 3 and 4B (pre-bagged mortar requirement applies to systems where mortar is the attachment component not systems utilizing ridge board and mechanical or adhesive-set).
- Utilize an additional tile factor of 2-1 above that specified in SSTD 11 or TAS 101 to determine the "allowable overturning moment" or "attachment resistance expressed as a moment (Mf)" conjoint systems.
- Prohibit component substitution without proper laboratory testing and FBC Product approval.
- Allow hip and ridge attachment systems with demonstrated performance equal or superior to that required by the identified systems.

installation instructions that existed before the guide, so in practice, the addition of the guide to the code should not have created a notable difference in wind resistance.

- ***Others:*** Require compliance with ANSI/SPRI ES-1 for edge flashings and copings.

2.2.4.4 Window Protection and Enclosure Classification

The need for window protection as a function of basic windspeed has changed only in the region of the Florida Panhandle. The Panhandle exemption was removed by the Florida legislature from the *FBC* in January 2007. The current windborne debris requirements in the Panhandle region require protection of glazed openings for all buildings located within areas having a design windspeed of 120 mph or greater.

Following the approach taken in the 2002 version of ASCE 7, the option to design buildings using the partially enclosed option was removed from the Florida Building Code in July 2007. The 2007 revisions also required that any glazed openings at any height above ground must be protected if they are located less than 30 feet above any gravel roof surface within 1500 feet of the opening.

A requirement that impact resistant coverings shall be tested at 1.5 times the design pressure (positive or negative) was introduced in December 2006. This requirement was automatically satisfied if impact covering were tested to the Miami-Dade County test protocols but not if the product was approved through the ASTM or SSTD-12 test standards. Thus, the introduction of this requirement resulted in all three standards requiring static testing at 1.5 times the design pressure. In practice, this change is expected to yield little or no change in the wind resistance of most impact resistant coverings.

2.2.4.5 Soffit Design

The 2006 amendments to the *FBC* required that all soffits be designed to resist the wind loads for components and cladding on the adjacent walls.

2.2.4.6 Rooftop Equipment

Provisions for rooftop equipment (RTE) have changed relative to the 2001 *FBC*. Specifically, design provisions have been clarified, and the attachment requirements for rooftop equipment have become more stringent. Initially, the 2001 *FBC Mechanical* stated that all rooftop equipment and supports must be designed and installed to resist wind pressures as per the *FBC Building*. In the 2004 version, this was elaborated upon by specifying that this may now be accomplished by design or by Section 301.13.1, which outlines anchorage requirements for rooftop equipment based on size for ground-mounted units. The use of wood "sleepers" was banned in the 2006 *FBC Mechanical* and the clarification that mechanical units and their supports must be secured to the structure was made. The use of "sleepers" in high velocity hurricane zones however, has not been permitted since at least the 2001 *FBC Building.* Clearance requirements contained within Chapter 15 of the *FBC Building* for raised RTE have remained unchanged.

Rooftop equipment is included in Section 5 as a secondary factor for flat-roof multi-family residences. The inspection criteria rely on determining if equipment is present and, if present, if the RTE is unrestrained or poorly restrained. The visual inspection approach allows a practical treatment of RTE that does not require engineering calculations or design documentation.

2.2.4.7 Performance Requirements

The only significant change with respect to the wind-resistive performance requirements is the adoption of the ASCE 7-02 standard to replace ASCE 7-98. The major effects of this change on design pressures are:

1. A change in the pressure coefficients on the roofs of hip and gable roof buildings with roof slopes in the 7 degree to 27 degree range.
2. A reduction in the uplift forces at the gable ends of gable roof buildings with roof slopes greater than 20 degrees and heights less than 60 feet due to the inadvertent elimination of a load case in ASCE 7-02 compared to ASCE 7-98. This change results in an underestimate of the uplift requirements for end trusses on all buildings having roof slopes of 5:12 and higher.

2.2.4.8 FBC Construction Eras

As previously discussed, the most significant changes to the FBC affect single family residences and, similarly, Group I multi-family residences.[5] Table 2-1 summarizes the effective dates of the changes to the *FBC* that are expected to have a notable impact on reducing wind losses to residential buildings. Construction permit applications received by the local building official after those dates would have to comply with the code provisions enacted prior to the effective date. Note that the date the construction permit is awarded generally lags the date the permit application was received.

For simplicity in the development of the loss relativities, we suggest that the *FBC* building code eras be divided into two periods: 2001 *FBC* (for residences with permit applications after March 1, 2002) and 2006 *FBC* (for residences with permit application after December 8, 2006). The most significant changes to the 2004 *FBC* took place in December 2006 and we believe that supplement provides sufficient changes for a new post-*FBC* construction era (see Table 2-2). Regarding code changes after that date, such as the 120 mph wind borne debris criteria in the Panhandle and the elimination of partially enclosed designs, the loss relativity tables allow for direct look-up and computation of the appropriate relativity for these cases.

Table 2-1. Summary of Effective Dates for FBC Code Changes Relevant to Wind Resistance

Effective Date	*Code Change*
October 1, 2005	(i) Introduction of ASCE 7-02 in place of ASCE 7-98 (*FBC Building*)
December 8, 2006	(ii) Ring-shank nails required for all roof sheathing connections for prescriptive designs. (iii) Soffits required to be designed to resist wall pressures. (iv) Option for ASTM D-7158 Class H (150 mph) shingles recognized for ≥ 130 mph zones. (v) Introduction of ASCE 7-02 (*FBC Residential*).
February, 2007	(i) Florida legislature passed law requiring 120 mph criteria to be used for the windborne debris region in the Panhandle.
July 1, 2007	(ii) Partially-enclosed design option removed from the *FBC.*

Table 2-2. FBC Construction Eras for Loss Relativity Analysis

Loss Relativity FBC Era	*Permit Application Dates*	*Year Built as an Approximate Surrogate for FBC Era*
FBC 2001	From March 1, 2002 to December 7, 2006	2003, 2004, 2005, 2006, 2007
FBC 2006 [FBC 2004 (with 2006 Supplement)][1]	From December 8, 2006 to current	2008, ……

[1] We will use a shortened reference for FBC 2004 (2006 Supplement) as FBC 2006.

Determination of FBC Era. There are several approaches for determining FBC era for insurance rating purposes. The first and foremost approach is to find out what code the building was built to. That is, the question should be "To what building code (and amendments) was the building built?" and not "What year was the building built?" The FBC requires that the structural drawings indicate building design information. For example, Figure 2-6 shows a drawing stamp that indicates the house was

[5] Section 2.5 discusses building models and groups.

designed to FBC 2001 as a fully enclosed building with 120 mph basic windspeed. The second approach is to verify the permit application date and use that to classify the building into the appropriate era. Permit application dates are generally available from the local Florida building department. For example, an insurer could ask the homeowner to provide that information if there was a question as to whether or not the home qualified as *FBC* 2001 or 2006.

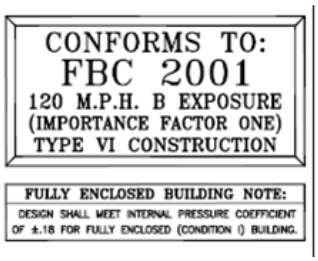


Figure 2-6. Example drawing stamp that shows FBC Construction.

A third, less accurate, approach, would be to use the year built as a surrogate to determine the appropriate *FBC* era. For example, homes built within the years 2003 and 2006 would most likely fall into *FBC* 2001 Era, while homes built in 2008 and later would fall into *FBC* 2006 Era. A year built of 2007 is more uncertain, but we placed it in the FBC 2001 era in Table 2-2 for reasons discussed in the following paragraphs. These year-built dates recognize the lag time between initial permitting and completion of the construction. It is clear however, that any year built approach is simply an approximate surrogate for *FBC* Era and would miss some homes that are actually *FBC* built homes. For example, a home whose permit application occurred after March 1, 2002 and was also completed in the same year would be missed by the surrogate years in Table 2-2. Similarly, a home with permit application in 2007 and completed in 2007 would be missed as *FBC* 2006 using the surrogate year built in Table 2-2.

The homeowner should always have the option of confirming whether or not the home is *FBC* (and which *FBC* Era) by providing construction permit application dates and or design drawing information. Since the rate differentials are significant for FBC construction, the homeowner has an economic interest in making sure the home receives the appropriate credit. From the insurer viewpoint, he has a clear economic interest in making sure that homes were actually built to the *FBC*. For example, an insurer that uses year built of 2001 or 2002 as automatic qualification for *FBC* 2001 Era would be granting rate differentials to many homes that were permitted before the *FBC* became effective. Since homes built prior to the *FBC* require an inspection to determine what rate differentials apply, the differences are significant in terms of both inspection cost and rate differentials.

Selection of Appropriate Relativity Table for FBC 2006 Era for Single Family and Group I Multifamily. The FBC 2001 and 2006 construction eras apply to single family homes and Group I multi-family residences. Our analysis of Group II and Group III multi-family residences includes only one era (FBC 2001) for all post-FBC construction.

The most important determination for either single family or multi-family is whether or not the building was permitted after March 1, 2002. This determination provides for FBC rate differentials. The differences between FBC 2001 and FBC 2006 are not as significant as the difference between pre-FBC and post-FBC. The loss relativity tables (in Sections 4 and 5 for post-FBC for single family and Group I MF) are given according to the FBC 2001 and FBC 2006 construction eras. The modeled buildings for FBC 2006 included ring shank nails and the 150 mph shingle in $\geq$ 130 mph wind zone. Hence, we recommend that the following conditions be met for single family and Group I MF residences permitted after December 8, 2006 to qualify for the FBC 2006 relativities:

1. Ring shank nails (8d or better) used for roof sheathing attachment that meets Deck Strength C.
2. ASTM D-7158 Class H shingles must be used if the building is located in $\geq$ 130 mph wind zone (which includes the HVHZ) and the roof cover type is asphalt shingles.

Otherwise, we recommend using the FBC 2001 relativity tables for FBC 2006 era single family and Group I multi-family residences. In using the FBC 2001 relativity tables for FBC 2006 construction that

doesn't meet the above conditions, use the wood soffit case.[6] These conditions match the way the buildings were modeled and provide a flexible way to look up the post-FBC relativities for the key FBC code changes that most influence the relativities. While adding some complexity to the selection of relativity tables, this approach provides a way to reflect the continued evolution and improvement of the FBC.

2.3 Hurricane Wind Hazard Modeling

The wind contours in Figure 2-3 (page 23) are based on the hurricane simulation model of Vickery et al. (2000), which has formed the basis of the national hurricane windspeeds given in ASCE 7 since 1998. This model is the basis for the wind model in HURLOSS and was used in the 2002 Loss Relativity Study.

There has been a significant amount of hurricane research since 1998. We highlight some of the new research as it affects the loss mitigation modeling in this project and the use of the HURLOSS model. The updated hurricane wind model in HURLOSS is based on Vickery et al. (2008a, b). This updated model has been reviewed and approved by the Florida Commission on Hurricane Loss Projection Methodology. In addition, the updated model has been presented to the ASCE Wind Committee and will likely be approved for the new hurricane wind maps in ASCE 7 in 2010.

The new model incorporates a significant amount of new flight level and surface level hurricane data. The new hurricane wind model research has focused on four areas:

1. Hurricane Windfield and Boundary Layer Model
2. New Intensity Model
3. New Statistical Models for B and Radius to Maximum Winds
4. Updated Filling Model

The details of the research are described in a series of papers (Vickery (2005), Vickery, et al. (2008a,b), Vickery and Wadhera, (2008)). These new data have resulted in an improved hurricane windfield model including the modeling of the sea-land transition and the hurricane boundary layer height, a new model for hurricane weakening after landfall, and a significantly improved statistical model for the Holland *B* parameter. The new statistical model for *B* results in an overall decrease in predicted hurricane induced windspeeds, even though the overall rate of intense storms (defined by central pressure) produced in the current model is increased compared to that produced in the Vickery, et al. (2000) model.

2.3.1 Hurricane Windfield and Boundary Layer Model

One of the major improvements has been in the implementation of a new hurricane boundary layer model that better represents the variation in windspeed with height within a hurricane. The new model has been extensively validated through comparisons of modeled and observed windspeeds using data from 25 different hurricanes, 13 of which affected Florida. Figure 2-7 shows comparisons of the variation of the modeled and observed windspeed with height produced by the hurricane boundary layer model. The comparisons show how the new boundary layer model incorporated within the windfield model agrees with the observations.

[6] The wood soffit results in the FBC 2001 results are essentially identical to the FBC 2001 results with designed soffit resistances.

The analysis of the dropsonde data (Figure 2-7) reinforced the conclusion of the study described in Powell, et al. (2003) that the roughness of the ocean does not continue to increase with increasing windspeed but in fact reaches a plateau, or maximum value.[7]

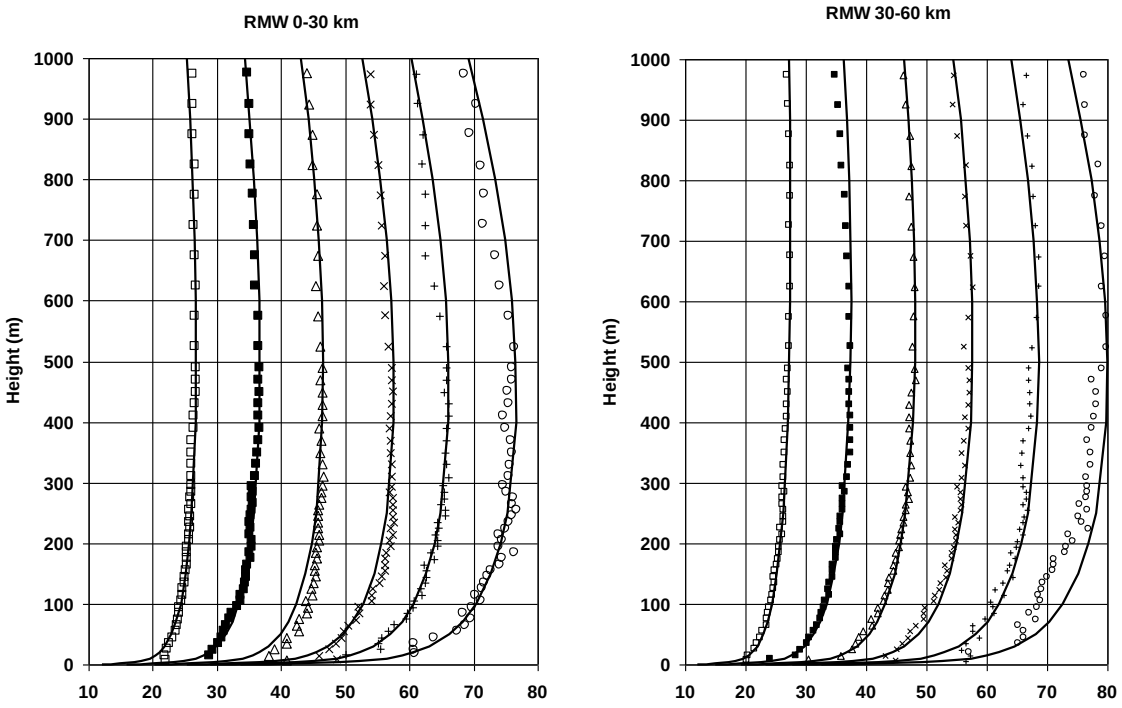


Figure 2-7. Comparisons of Modeled and Observed Hurricane Mean Velocity Profiles over the Open Ocean for a Range of Windspeeds.

Figure 2-8 presents the gust windspeed ratios derived from the Vickery, et al. (2008a) model (near the RMW), the ratios derived from the Vickery, et al. (2000a) model (also near the RMW) and those derived from ASCE 7. The windspeed ratio is defined as the open terrain gust windspeed (defined here as z_o = 0.03m) divided by the marine gust windspeed. Thus, for Exposure D, the ratio is equal to $1/\sqrt{K_z}$ where K_z is the exposure height factor used in ASCE-7. As indicated in Figure 2-8, the windspeed ratios produced by the new windfield model are similar to the ratios associated with Exposure D for all windspeeds, whereas the for large windspeeds, the windspeed ratio associated with the older model, using a drag coefficient that does not have an upper limit, approaches that of Exposure C in ASCE 7.

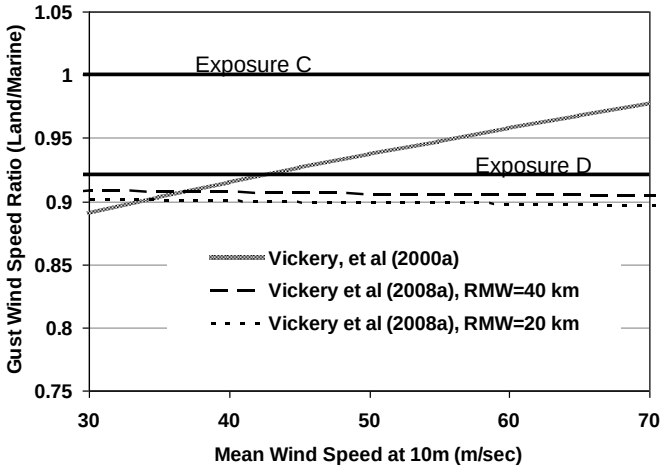


Figure 2-8. Gust Windspeed Ratio (Gust Windspeed on Land Divided by Gust Windspeed over Water). A Gust Windspeed Ratio of 1 Indicates No Reduction in Windspeed as Wind Moves from Sea to Land (i.e., Marine Roughness is the Same as Open Terrain).

[7] Previous research had suggested that the surface roughness of the ocean continued to increase with increasing windspeed (Powell, 1980, Garratt 1977, Vickery and Skerlj, 2000).

Table 2-3 summarizes the numbers of comparisons of modeled and observed windspeeds that have been performed using the hurricane windfield model. These 258 comparisons include only those where the maximum windspeed at the location of the anemometer was recorded. Numerous additional comparisons have been performed using partial windspeed traces, where the windspeed recording system failed before the maximum windspeed was recorded. Examples include C-MAN location FWFY1 in Hurricane Andrew and ASOS station KPGD in Hurricane Charley. Example comparisons of modeled and observed windspeeds (mean and gust), wind directions, and pressures are shown in Figure 2-9. Figure 2-10 presents scatter plots of modeled and observed maximum peak gust windspeed for 24 hurricanes. More detailed examples of comparisons of modeled and observed windspeeds, as well as estimates of the variation of the maximum gust windspeeds produced by some of the hurricanes affecting Florida in 2004, appear in Appendix B.

Table 2-3. Number of Windspeed Records for Each Hurricane.

Year	*Hurricane Name*	*Number of complete windspeed records*			*Number of complete windspeed records*	
		Land	*Marine*	*Total*	*Inside RMW*	*Outside RMW*
1979	Frederic	4	--	4	2	2
1985	Elena	3	2	5	2	3
1989	Hugo	6	1	7	5	2
1991	Bob	2	5	7	4	3
1992	Andrew	1	2	3	1	2
1993	Emily	--	9	9	4	5
1995	Erin	5	2	7	5	2
1995	Opal	5	2	7	5	2
1996	Bertha	5	3	8	5	3
1996	Fran	9	3	12	6	6
1998	Bonnie	2	4	6	6	--
1998	Georges	3	10	13	8	5
1999	Floyd	2	4	6	4	2
1999	Irene	4	5	9	3	6
2003	Isabel	10	7	17	5	12
2004	Charley	12	1	13	4	9
2004	Frances	13	1	14	9	5
2004	Ivan	15	6	21	7	14
2004	Jeanne	17	2	19	8	11
2005	Dennis	9	3	12	2	10
2005	Katrina	8	2	10	2	8
2005	Ophelia	5	7	12	6	6
2005	Rita	14	--	14	6	8
2005	Wilma	21	2	23	20	3
	Total	175	83	258	129	129

2.3.2 New Intensity Model

The changes to the hurricane intensity model are described in detail in Vickery, et al. (2008b). The major changes to the intensity portion of the model include the redevelopment of the equations that compute the intensity of a model hurricane as it moves across the ocean. The net result in Florida of the changes to the model (compared to the model described in Vickery, et al., 2000b) is an increase in the rate of landfall of intense hurricanes as defined by central pressure (not windspeed) at the time of landfall. Figure 2-11 presents a comparison of the landfall frequencies of Intense Hurricanes (IH) as defined by central pressure at the time of landfall derived from the Vickery, et al. (2008b) model, the Vickery, et al. (2000b) model, and the historical data. The historical data covers the period 1900 through 2007. As

indicated in Figure 2-11, the newer model yields more IH landfalls per year than the Vickery, et al. (2000b) model; but in all cases, except GA/SC where the old model over- estimates landfall frequency, the estimates from either model fit within the 95% uncertainty bounds associated with the observations.

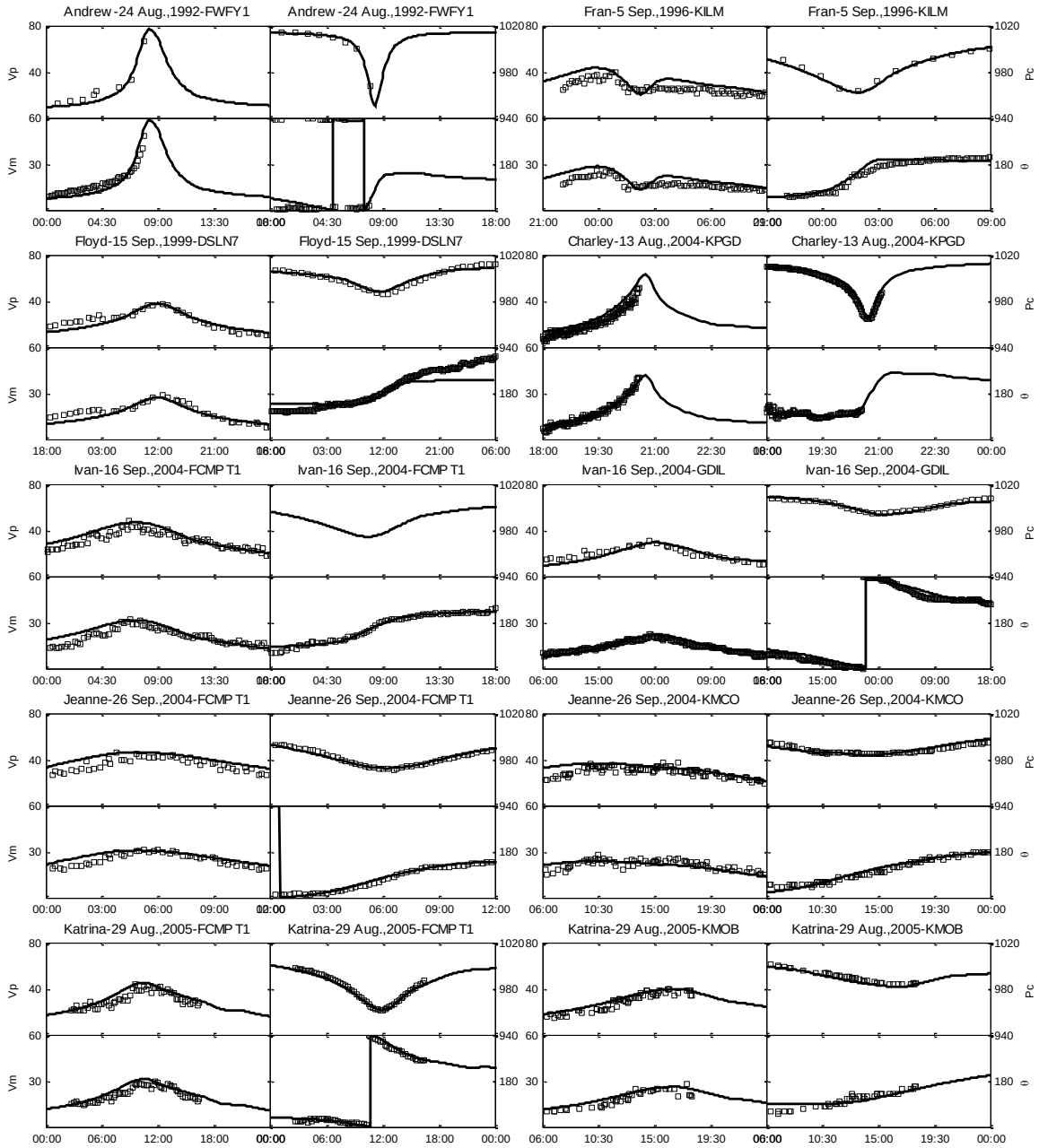


Figure 2-9. Example Plots Showing Modeled and Observed Windspeeds, Surface Pressures and Wind Directions. Model Results Represented by Solid Line, Observed Values Represented by the Open Squares. Modeled Mean Windspeed Representative of a One-Hour Average. Averaging Time for Observed Windspeeds are 10 min at FWYF1, DSLN7, and GDIL1. Averaging Time for Observed Winds at FCMP T1 are 15 Minutes. Averaging Times for Mean Winds at KPGD, KMOB, KILM, and KMCO are 2 Minutes. Windspeeds are given in m/sec. Vm represents the mean windspeed; Vp represents the gust windspeed; Pc represents the central pressure, and θ represents wind direction.

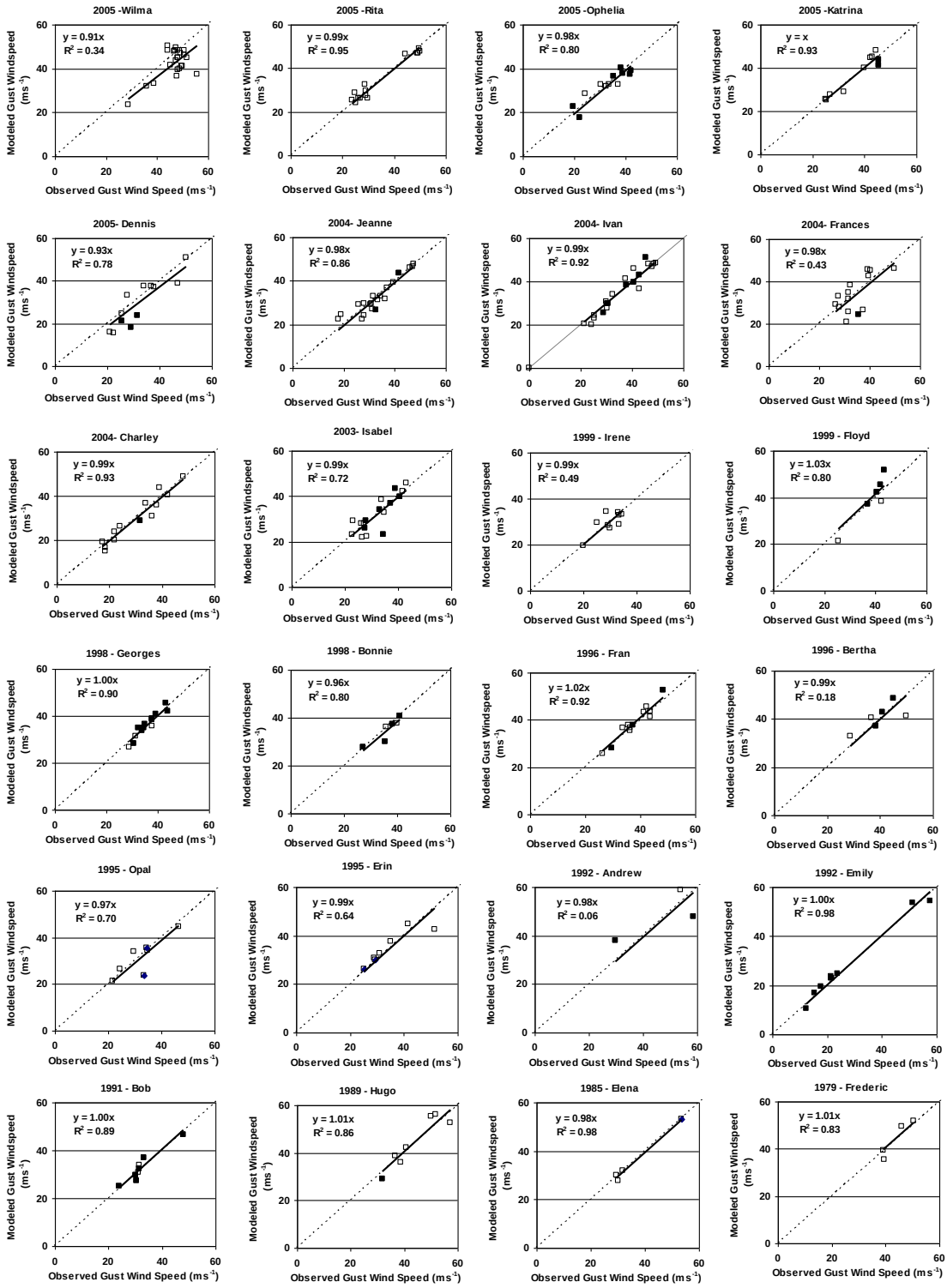


Figure 2-10. Comparison of Modeled and Observed Maximum Peak Gust Windspeeds for 24 Land Falling Hurricanes. Open Squares Represent Land-Based Measurements; Solid Squares Represent Marine Based Measurements. All Windspeeds are at a Height of 10m in Either Open Terrain or Marine Conditions.

2.3.3 New Statistical Models for B and Radius to Maximum Winds

Using new aircraft measurements of pressures obtained by NOAA during the period 1977 to 2003, we fit the radial distribution of pressures to determine the values of the radius to maximum winds (*RMW*) and the Holland pressure profile parameter (*B*) that best models the pressure field. Figure 2-12 presents some examples of modeled and observed pressures.

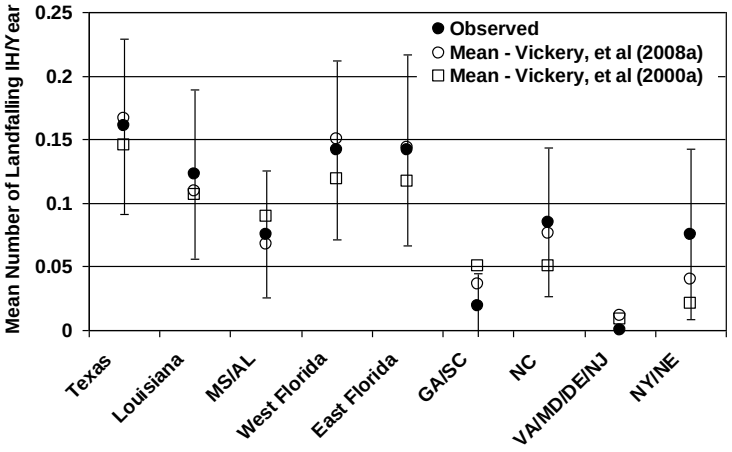


Figure 2-11. Comparison of Modeled and Observed Annual Landfall Rate of Intense Hurricanes (Simulated and Observed IH Frequencies Based on Hurricane Central Pressure at Time of Landfall).

The *B* values obtained from all the hurricanes were analyzed and it was found that *B* decreases with increasing *RMW* and with increasing latitude. A weak positive relationship between *B* both Δp and sea surface temperature, T_s, was also found.

Figure 2-13 shows *B* plotted as a linear function of the *A* (*A* = nondimensional variable, see Wadhera and Vickery (2008)), where it is clearly seen that as *A* increase, *B* decreases. The new linear model relating *B* to *A* developed using a data set that is approximately twice the size of that used to develop the previous model for *B* reduced the error in the modeling of *B* from 0.38 to 0.26, and also had the effect of reducing the mean value of *B*. The net effect of the new statistical model for the Holland *B* parameter was a reduction in predicted windspeeds, and hence losses.

New statistical models for the radius to maximum winds resulted in a statistical model that yielded smaller hurricanes in the Gulf of Mexico compared to the prior model.

2.3.4 Updated Filling Model

A new filling model describing the rate of increase of the central pressure (or decrease in the central pressure difference) has been implemented in the hurricane simulation model. The exponential decay model is described in detail in Vickery (2005). The central pressure difference *t* hours after landfall is described by a negative exponential function, where the rate of decay is characterized by a parameter that increases with a parameter defined by $\Delta p \cdot c/RMW$ where Δp is the central pressure difference at the time of landfall, *c* is the translation speed of the hurricane and *RMW* is the radius of maximum winds. The data indicate that small, fast and intense hurricanes decay more rapidly than large, slow moving weak hurricanes. Figure 2-14 shows comparisons of the filling coefficient, *a*, plotted vs. $\Delta p \cdot c/RMW$ for hurricanes making landfall in Florida. The Gulf coast filling model is used for hurricane making landfall along the Florida Gulf coast west of 84°W. The Atlantic coast filling model is used for hurricanes making landfall along the Atlantic coast of Florida north of 29.5°N. Hurricanes making landfall elsewhere in Florida are filled using the Florida Peninsula model.

Figure 2-15 presents the exponential decay constant, *a*, plotted vs. Δp where it is evident that a relationship between the filling constant *a*, and Δp is not nearly as strong as the relationship between the filling constant and $\Delta p \cdot c/RMW$ as indicated in Figure 2-15. Also shown in Figure 2-15, as a dashed line, is the filling constant *a* described in Vickery and Twisdale that was used in the prior version of the hurricane hazard model. The previous version of the filling model did not capture the rapid decay of the small fast moving intense hurricanes, which is handled with the updated model.

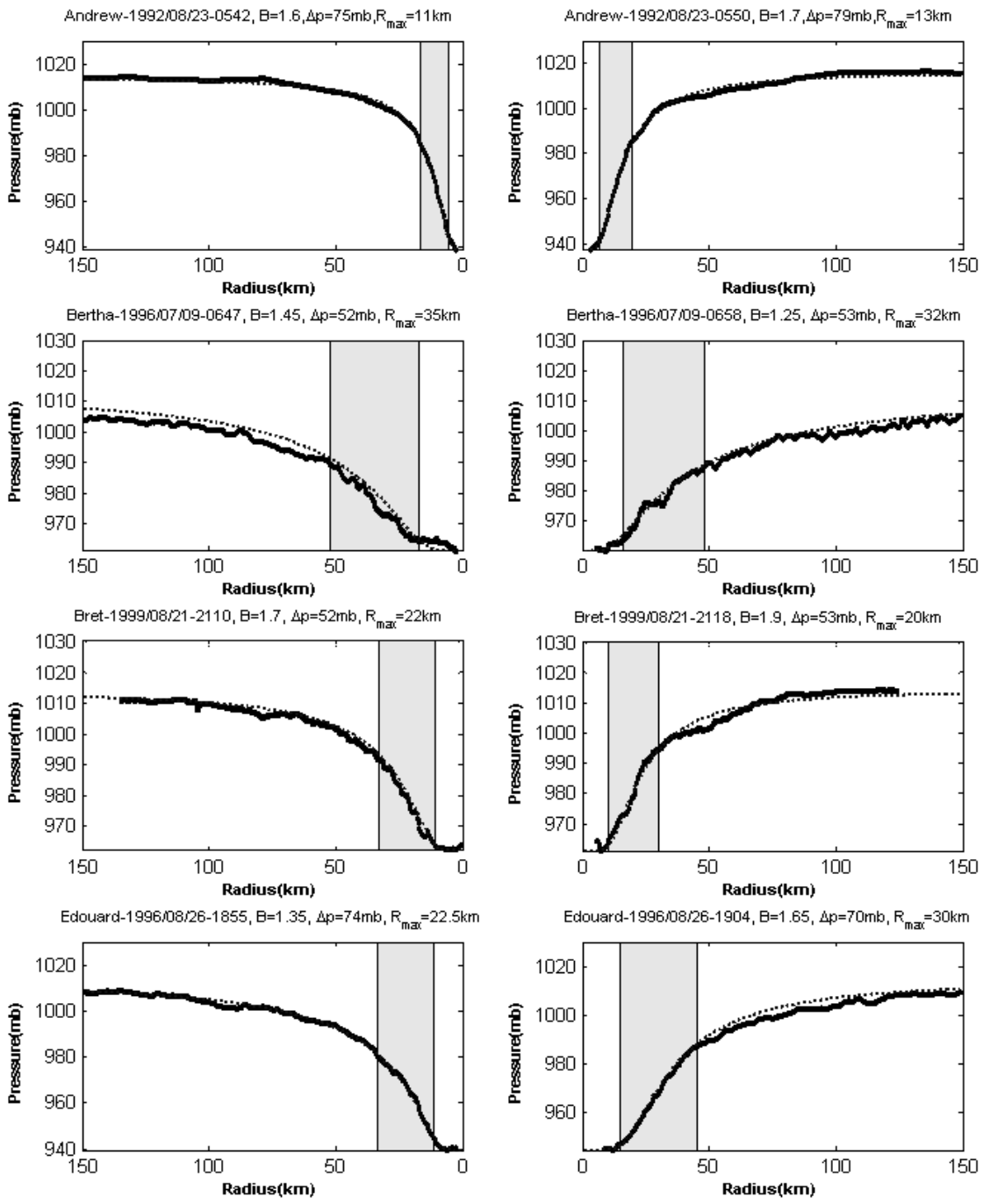


Figure 2-12. Comparisons of modeled and measured radial profiles of pressure in hurricanes

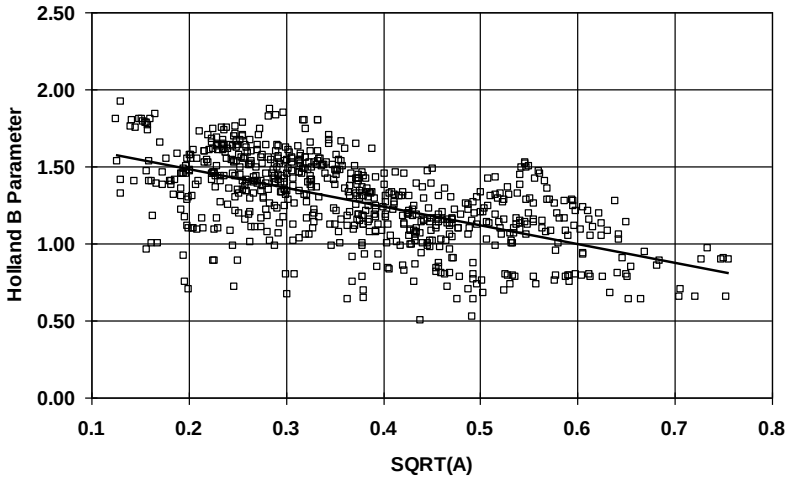


Figure 2-13. Relationship between the Holland B Parameter and the Dimensionless Parameter, A.

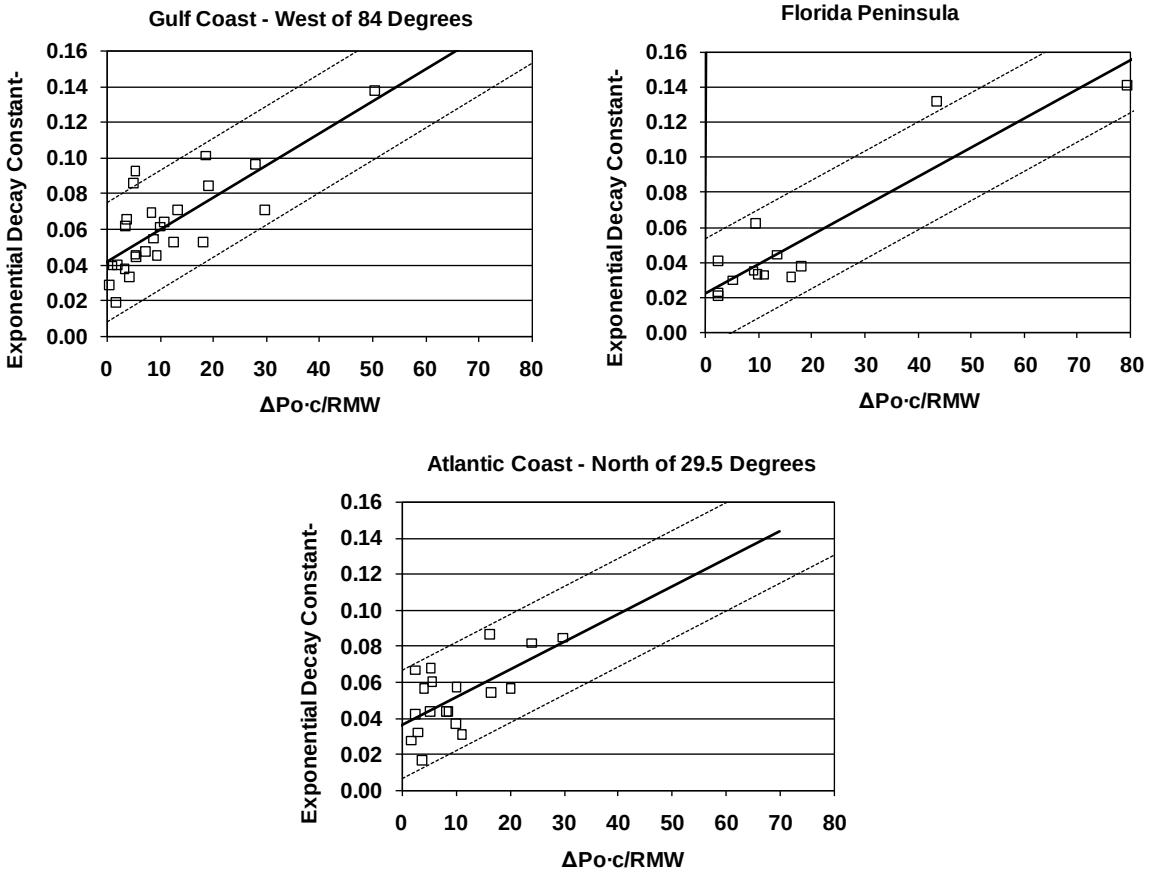


Figure 2-14. Filling Constant, a, vs. $\Delta p_o c/RMW$, Where Solid Line Represents Linear Regression Line and Thin Dashed Lines Represent the Mean Error $\pm 2\sigma_\varepsilon$.

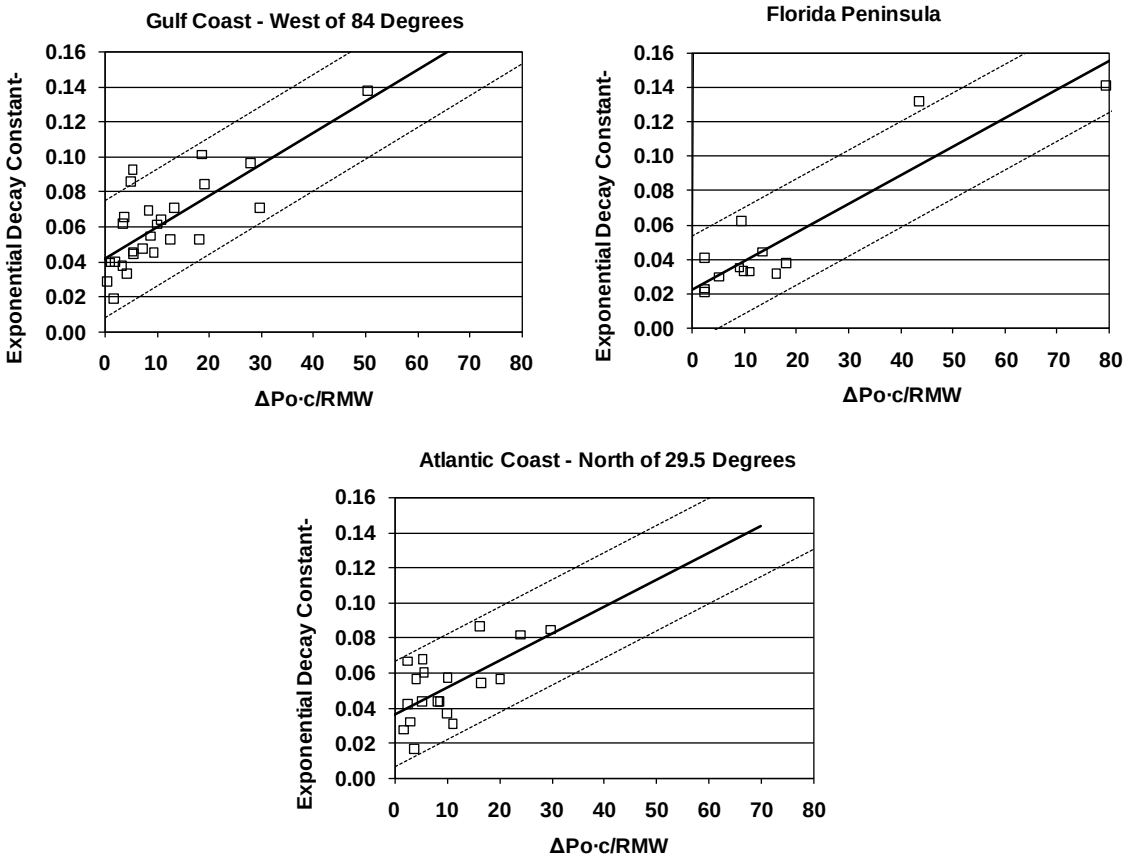


Figure 2-15. Filling Constant, a, vs. Δp_o, Where Solid Line Represents Linear Regression Line, Thin Dashed Lines Represent the Mean Error $\pm 2\sigma_\varepsilon$, and Bold Dashed Line Represents the Vickery and Twisdale (1995) Model Used in the 2002 Relativity Studies.

2.3.5 Wind Hazard Maps

Figures Figure 2-16 and Figure 2-17 show maps of the modeled peak gust windspeeds for various return periods for the entire United States derived from a 100,000-year simulation of hurricanes using the new hurricane model. In the case of Florida, there is an overall decrease in the windspeeds for a given return period. This decrease is brought about primarily because of the new statistical model for the Holland B parameter.

These maps include the treatment of uncertainties in central pressure and Holland B parameter. Estimates of uncertainties in the predicted windspeeds are obtained by propagating the uncertainties in the key model inputs through to the windspeed prediction stage. The two parameters controlling the overall windspeed prediction uncertainty are the central pressure and the Holland *B* parameter. These two parameters are responsible for ~95% of the overall windspeed modeling uncertainty. The total uncertainty in the estimated 100-year return period windspeed is about 12%, varying somewhat with location. The inclusion of the windfield modeling error term derived from 258 comparisons of modeled and measured windspeeds results in an upwards shift of the windspeed vs. return period curve, with an average increase in the estimated 100-year return period windspeed of about 3%.

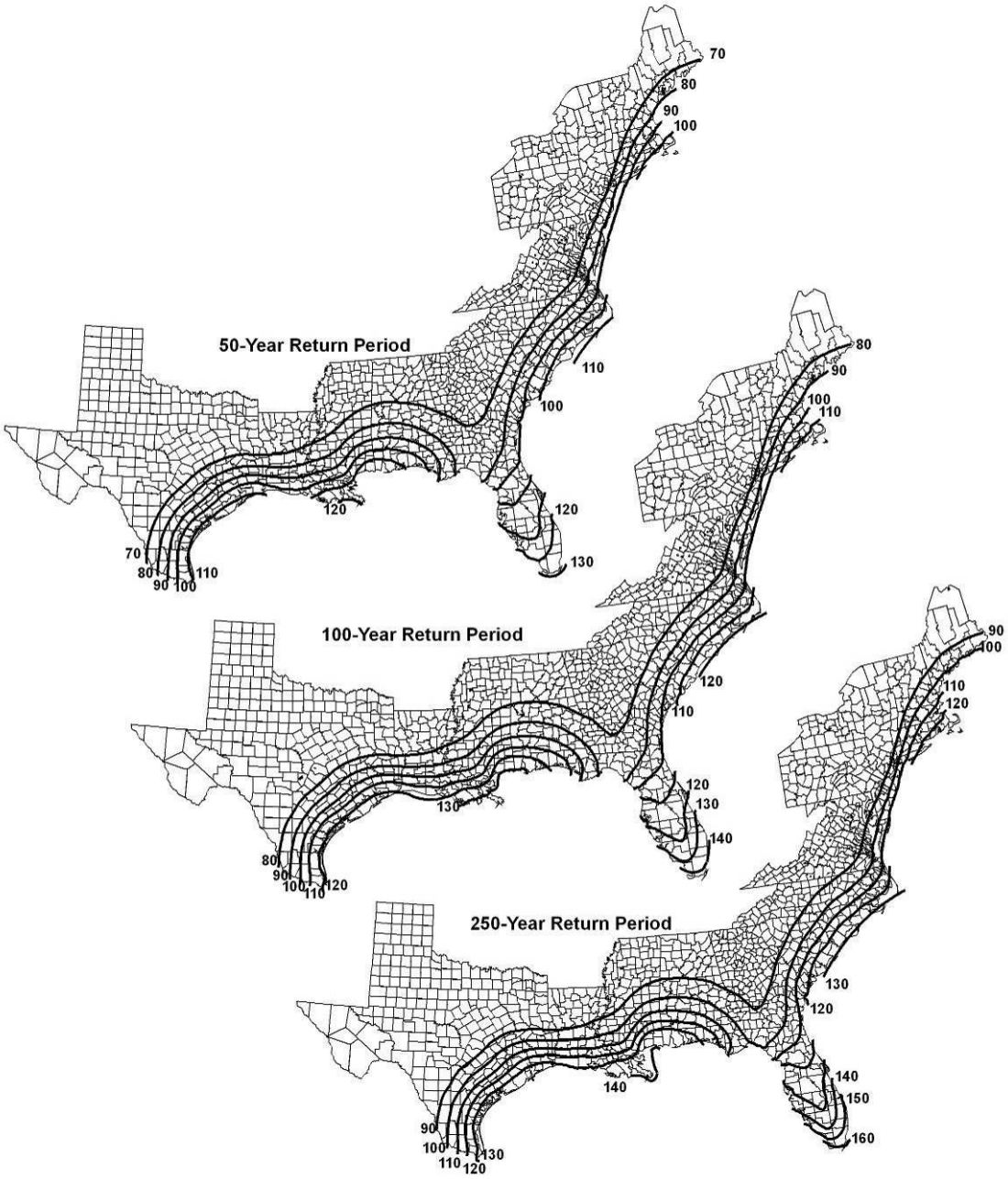


Figure 2-16. Model Estimated 50-, 100-, and 250-year Return Period 3-second Gust Windspeeds at a Height of 10 m in Open Terrain Including Wind Modeling Uncertainty.

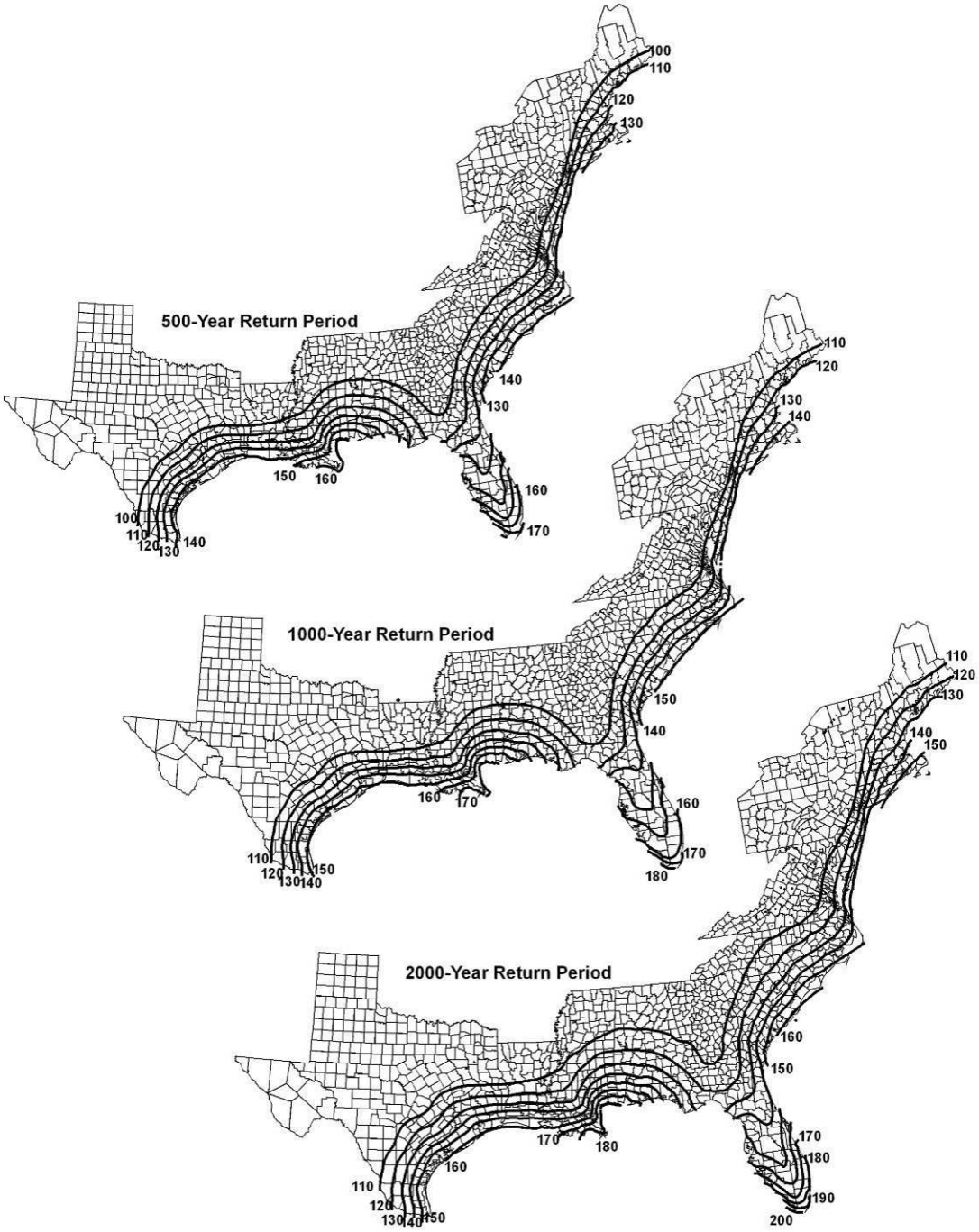


Figure 2-17. Model Estimated 500-, 1000-, and 2000-year Return Period 3-second Gust Windspeeds at a Height of 10 m in Open Terrain Including Wind Modeling Uncertainty.

2.3.6 Wind Climate Cycles/Change

These hurricane windspeed maps reflect the long term average risk as defined by the landfalling hurricane history in the United States over the past 107 years. These risk estimates include potential modeling errors, but they do not account for the possibility of short-term climate cycles or long-term climate change. While there are a number of researchers (e.g., Emanuel, 2005, Webster, et al. 2006) who suggest that hurricane activity is increasing, there is also another group of researchers (e.g., Landsea, et al., 2006, Landsea, 2007) who believe the recent increase in activity is part of an expected multi-decadal cycle.

Buildings and structural systems generally have a useful life of 40 to 100 years. Hence, for a structure built to today's design windspeeds, risk from future climate cycles is not likely to be significant since climate changes slowly compared to building lifetimes. Furthermore, there is greater risk variability during the design life of a structure due to the inherent randomness resulting from the "hit and miss" nature of hurricanes than there is from other uncertainties. That is, some structures may be hit by a hurricane significantly more intense than their design windspeed, but many other structures will never experience their design windspeed during their design life. These factors tend to ameliorate the concerns over climate cycles/change when one is practically assessing risks and unknowns to structures with very limited lifetimes in a geologic sense.

In summary, we do not include any special considerations of wind climate cycles or climate change in the hurricane modeling for wind mitigation loss relativities.

2.4 Locations for Loss Relativity Study

The FBC design windspeeds in Florida range from 100 mph to 150 mph peak gust winds in open terrain. In addition, there are two counties in the HVHZ that have specified county-wide design windspeeds (140 mph for Broward County and 146 mph for Miami-Dade County). If we consider the HVHZ design requirements separately, and use the 10 mph increments in the FBC design map, the entire state can be analyzed with eight wind zones:

1. 100 mph
2. 110 mph
3. 120 mph
4. 130 mph
5. 140 mph
6. 150mph
7. HVHZ Broward:140 mph
8. HVHZ Miami-Dade: 146 mph

The design requirements in these wind zones have changed over time, but these changes will be dealt with separately in the post-FBC building designs. Given these discrete wind zones, we must determine point locations for the analysis of losses. Modeled buildings will be situated at each location for the purpose of the hurricane damage and loss analyses. Since we will normalize the results at each location for each building by the computed (location-dependent) loss costs for that building, the consideration of multiple locations serves to test how the relativities may vary by location within the state.

2.4.1 Location Points

We developed the point locations by examining the current FBC windspeed map (which is based on 1998 hurricane modeling data and technology) and a new map, which is based on the previously described research. The current FBC map and a new map are shown in Figure 2-18. The current FBC

windspeeds are the red contours and the new windspeeds are the black contours. There are notable differences in the design windspeeds in the upper half of the state. These hurricane modeling updates will affect the relativities, but the changes in relativities willnot be as dramatic as the changes in the map since the relativities are normalized at each location.

We selected points for the wind mitigation study by locating points on the current FBC wind contours with consideration of the new hurricane model map. Many of the selected points are intersections of the current map and the new map. Intersection points were chosen to give us the most information on the differences in the hurricane wind contours from the old map to the new map. Several points were maintained from the 2002 Loss Relativity Study (points 16, 17, and 18).

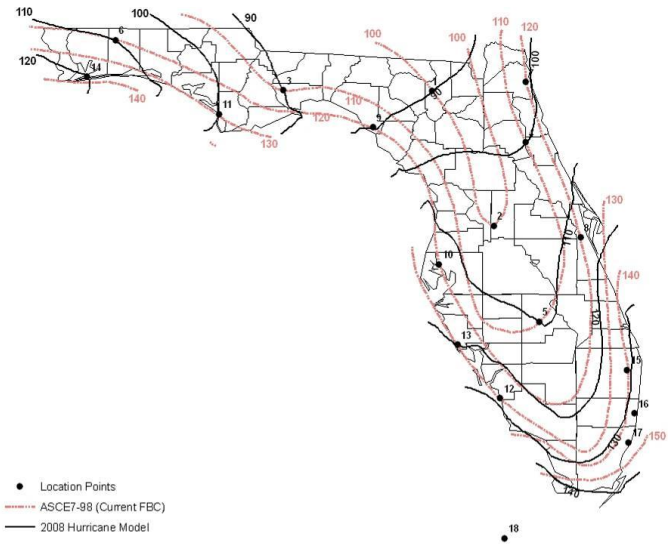


Figure 2-18. Current FBC and New Hurricane Model Wind Contours.

Figure 2-19 shows the 18 location points. We believe we have a good geographic spread and a sufficient number of points in each Florida windspeed zone for developing loss relativities by wind zone, if needed. We plan to develop the relativities by location and wind zone and then determine if averaging over wind zones introduces unacceptable error in the loss relativities. Recall that the 2002 studies used a single set of relativities for the entire state by averaging over all the analysis points.

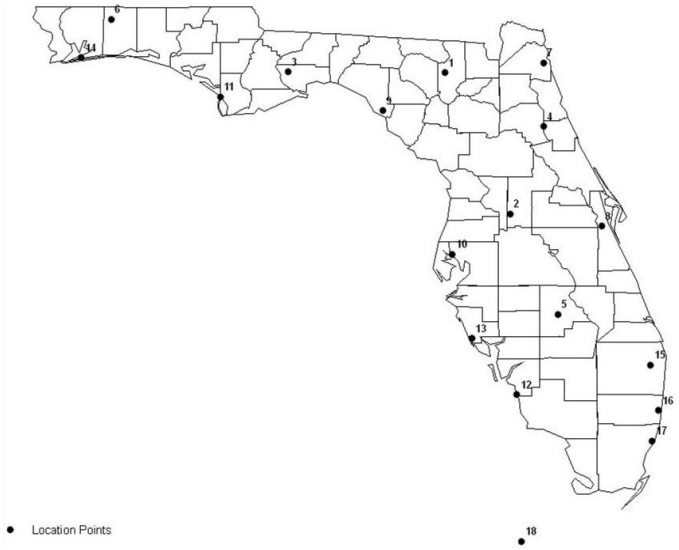


Figure 2-19. Final Location Point Map.

Table 2-4 provides the county, latitude, and longitude for each location point. We have 2, 3, 5, 3, and 2 points for the 100, 110, 120, 130, and 140 mph windspeed contours, respectively. There are two points in the HVHZ and one point in Monroe County.

2.4.2 Hurricane Wind Climate Simulation Approach

The Florida hurricane wind climate has been computed in several steps for this study. These steps have included selecting the length of the hurricane wind climate simulations, performing the simulations, developing a stratified sample for production runs, and verifying that the stratified sample is sufficiently accurate for use in the study.

Length of Simulations. We selected 500,000 years as the length of the wind climate simulations. In the 2002 study, we used 300,000 years and performed statistical analysis on the convergence of the loss costs produced by 300,000 year simulations. The statistical analysis showed that for a Miami location, that 300,000 years produced a standard error of 0.67% in the relativity for a weak house and

Table 2-4. Location Points for 2008 Florida Loss Relativity Wind Mitigation Study.

ID	ASCE 7-98 Windspeed Contour (mph)	New Model Windspeed Contour (mph)	County Location	Latitude (degrees)	Longitude (degrees)	Comment
1	100	90	Columbia	30.21000	-82.69000	(100, 90) Intersection point
2	100	~105	Lake	28.51000	-81.91000	(100,~105)
3	110	90	Wakulla	30.22000	-84.57000	(110, 90) Intersection point
4	110	100	Flagler	29.56000	-81.51000	(110,100) Intersection point
5	110	110	Highlands	27.30000	-81.34000	(110, 110) Intersection point
6	120	110	Okaloosa	30.85000	-86.68000	(120, 110)
7	120	~100	Duval	30.32542	-81.50699	(120,~100) Identical to 2002 West Jacksonville
8	120	~115	Brevard	28.36000	-80.81000	(120,~115)
9	120	90	Taylor	29.75000	-83.43000	(120, 90) Intersection Point
10	120	~114	Hillsborough	28.02000	-82.60000	(120, ~114)
11	130	100	Gulf	29.92000	-85.38000	(130,100) Intersection Point
12	130	~128	Collier	26.33000	-81.83000	(130,~128)
13	130	120	Sarasota	27.01000	-82.37000	(130,120) Intersection Point
14	140	120	Santa Rosa	30.39000	-87.04000	(140,120) Intersection Point
15	140	~127	Palm Beach	26.69000	-80.23000	(140,~127)
16	140	130	Broward	26.14289	-80.13958	HVHZ: Broward (Identical to 2002)
17	146	~136	Miami-Dade	25.77570	-80.21093	HVHZ: Miami-Dade (Identical to 2002)
18	150	~142	Monroe	24.56286	-81.77521	Key West (Identical to 2002)

0.64% for a strong house. In addition, we have found that to meet the Florida Commission on Hurricane Loss Projection Methodology standards (standard error of 2.5% or less), that 300,000 years did meet the standard for loss cost estimation in all Florida counties.

Simulation Results. We have completed 500,000 years of simulated hurricanes for each of the 18 points. Plots of windspeed vs. return period are given in Figure 2-20 for all 18 points. These plots show return periods from 10 to 10,000 years. The windspeeds correspond to peak gust winds in open terrain at 10 m above grade.

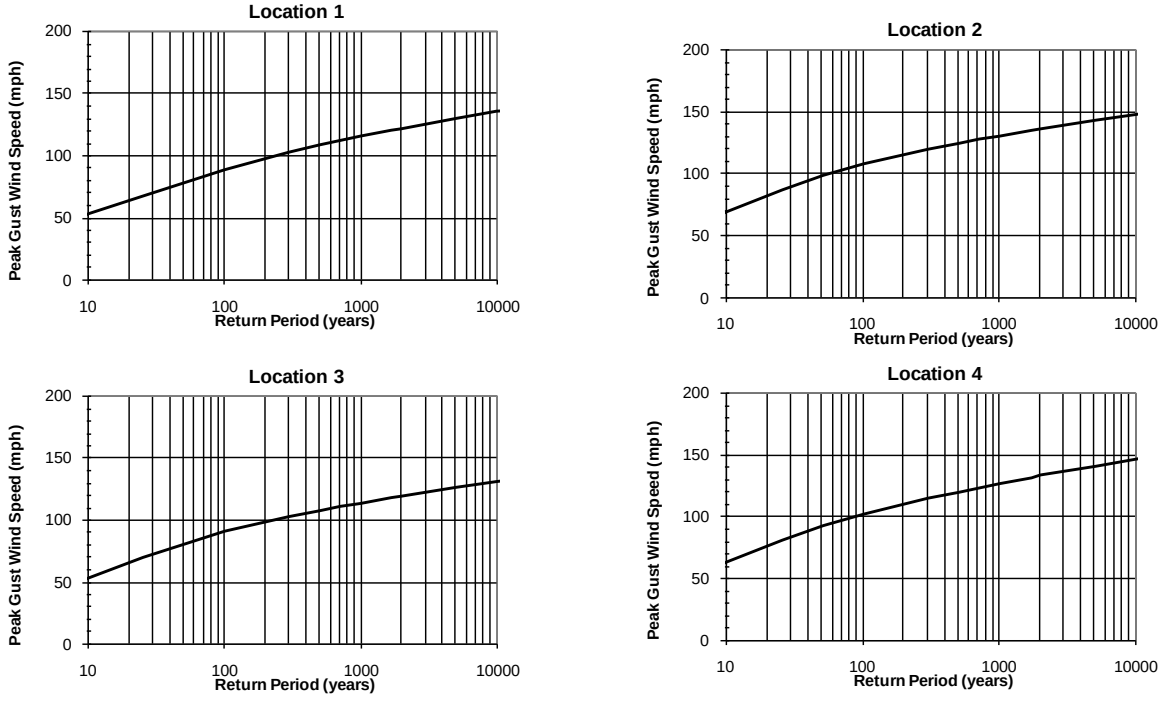


Figure 2-20. Windspeed vs. Return Period for 18 Locations.

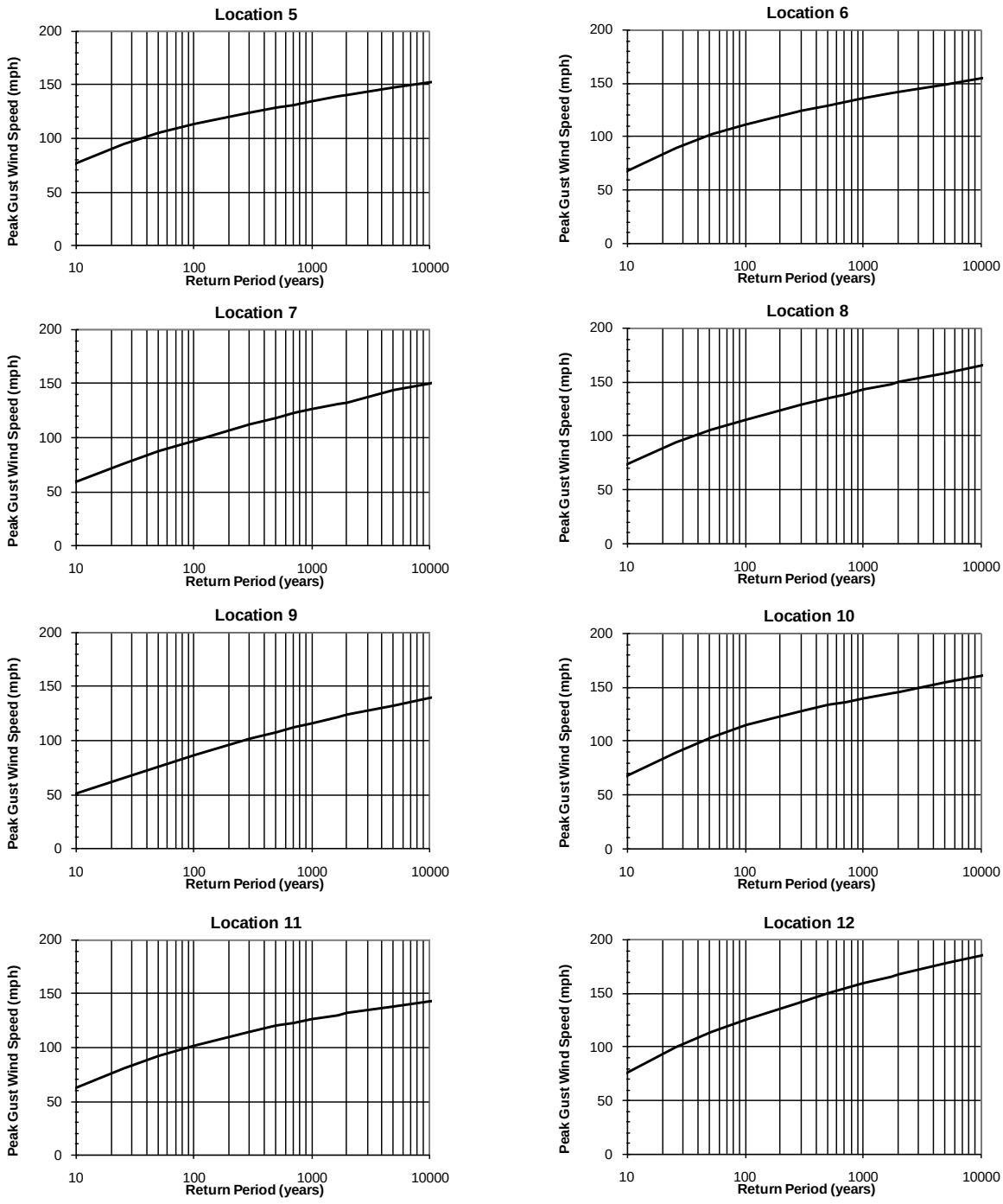


Figure 2-20. Windspeed vs. Return Period for 18 Locations (continued).

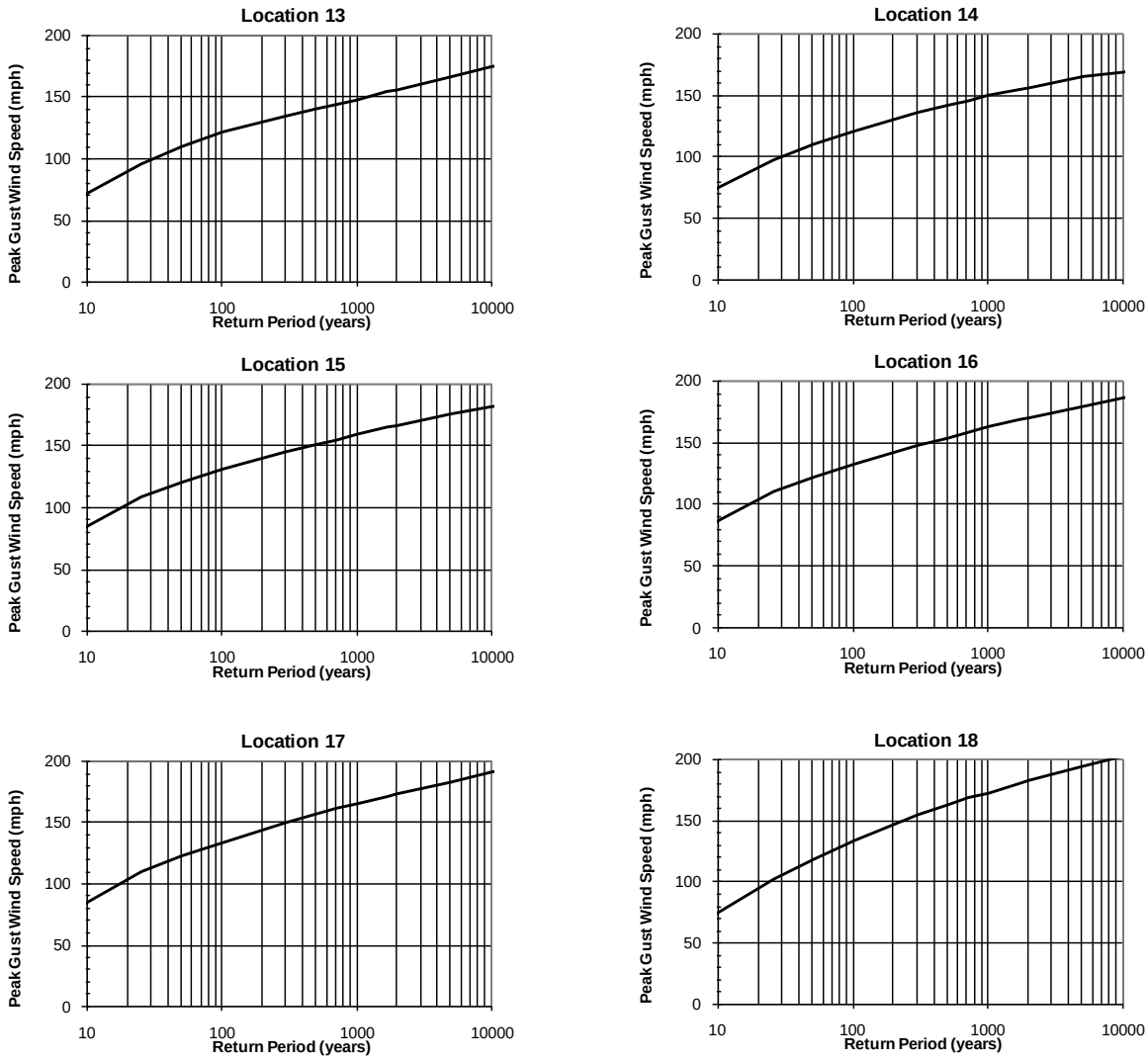


Figure 2-20. Windspeed vs. Return Period for 18 Locations (continued).

Development of Stratified Sample for Production Runs. In order to speed-up the many building loss calculations that have to be performed in this study, we have stratified the 500,000 years of hurricanes and incorporated a weighted sampling approach to improve the simulation efficiency.

Figure 2-21 shows the number of simulated storms producing a maximum windspeed within a 5 mph bin for locations 17 and 13, before and after the application of a stratified sampling weighting function. The weighting function focuses the computations on the less frequent but more damaging storms that control the average annual loss estimates. Also shown in Figure 2-21 are the windspeed vs. return period estimates (windspeed hazard) at locations 13 and 17 computed from the weighted storm set. As seen in Figure 2-21 the hazard curves at these two locations are well behaved out to return periods of 500,000 years; and through comparisons with the plots given in Figure 2-20, the resulting windspeed hazard curve developed using the weighted storm set is identical to that produced with the full storm set. Table 2-5 summarizes hurricanes that will be used in the loss mitigation computations using the stratified sampling approach. The simulated hurricane windspeeds have thus been developed using the stratified sampling approach and the data are stored and ready for the building damage and loss simulations.

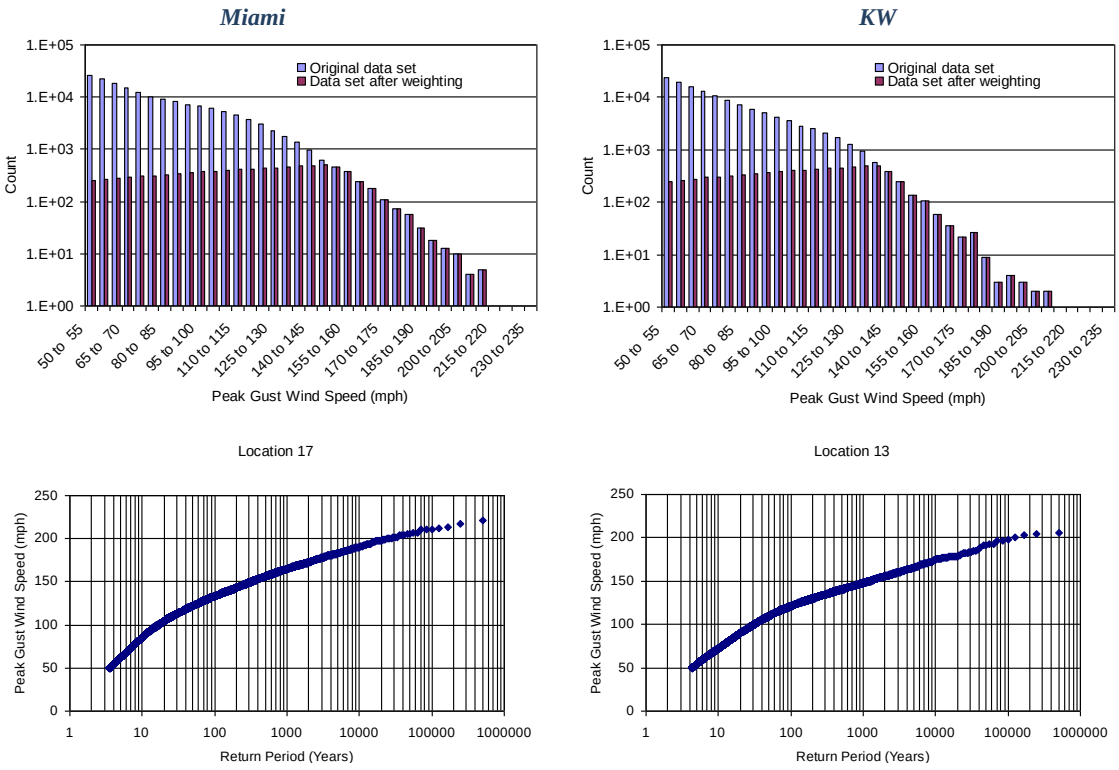


Figure 2-21. Stratified Sampling Approach.

Table 2-5. Summary of Total Number of Events Before and After Application of Stratified Sampling Weighting Function.

Location	*Number of Events Before Weighting*	*Number of Events After Weighting*
1	61,918	5,431
2	120,857	6,535
3	62,727	5,199
4	100,915	6,190
5	148,193	6,783
6	111,698	6,930
7	82,501	6,141
8	142,014	7,424
9	52,722	5,271

Location	*Number of Events Before Weighting*	*Number of Events After Weighting*
10	113,784	7,146
11	95,396	6,190
12	141,332	8,485
13	131,032	7,788
14	137,156	7,877
15	168,768	8,579
16	170,296	8,811
17	165,966	9,071
18	136,332	9,523

2.4.3 Frequencies of Hurricane Winds by Location

The following paragraphs summarize analysis of the hurricane wind risk frequency and intensity by location. We have analyzed the simulated hurricane data by location point to illustrate the differences in the hurricane wind risk characteristics. Figure 2-22 shows the average number of hurricanes per 100 years according to 4 windspeed intervals: < 100 mph, 100-120 mph, 120-150 mph, and > 150 mph). We see that the average number of hurricanes varies significantly across the state, ranging from about 6 to about 25 events per 100 years.

Greater than 120 mph. There is also a significant difference in the number of events that are greater than 120 mph, as illustrated in Figure 2-23. Points in SE Florida average more than 2 per 100 years while some locations in North Florida away from the coast average less than 0.1 per 100 years. The ratio of the number of events greater than 120 mph for each location to Location Point 3 (the minimum) is illustrated in Figure 2-24. There are more than 20 times as many > 120 mph events for South Florida than Point 3. This ratio illustrates the dramatic differences in the frequency and intensity of events by location within the State. Events greater than 120 mph are of particular interest because at those windspeeds one begins to see some notable building envelope failures in weaker construction.

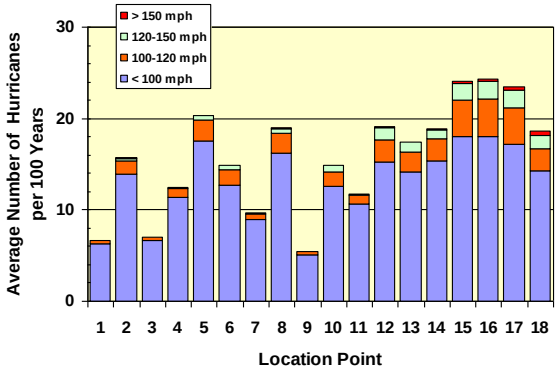


Figure 2-22. Average Number of Hurricanes by Location and Peak Gust Windspeed.

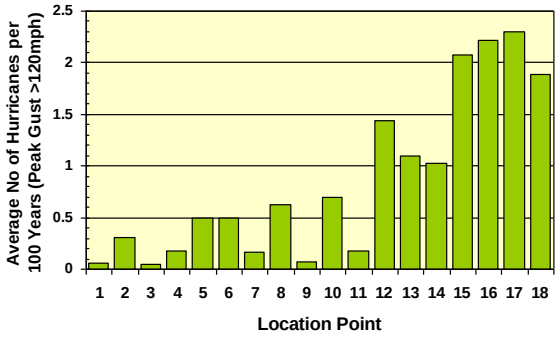


Figure 2-23. Average Number of Hurricanes with Winds > 120 mph.

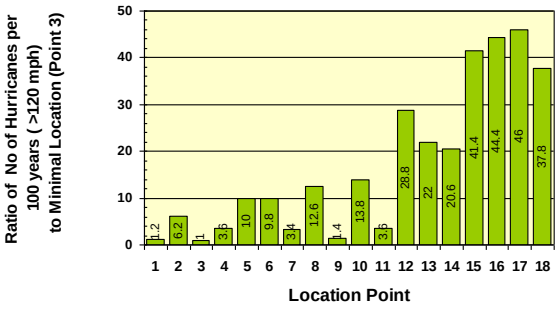


Figure 2-24. Ratio of Number of Hurricanes per 100 Years with Winds > 120 mph to Point 3.

Greater than 150 mph. Figure 2-23 compares the average number of hurricane events producing greater than 150 mph windspeeds by location. More locations drop out of this plot, and we see that Points 12, 15, 16, 17, and 18 stand out. Point 18 (Key West) leads this group.

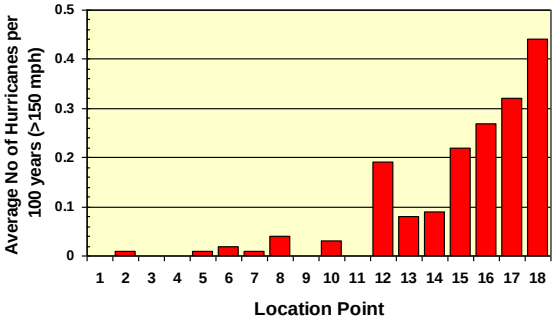


Figure 2-25. Average Number of Hurricanes per 100 years with Winds Greater than 150 mph.

Frequencies Relative to Design Winds. Figure 2-26 compares the average number of events that are less than and greater than the FBC design windspeed at each location per 100 years. The number of events that are less than the design windspeeds ranges from about 5 to more than 20 per 100 years. The numbers of events that exceed the design windspeed per 100 years averages less than one. Clearly, all locations in Florida will see many more hurricane wind events below their design windspeeds than those that are greater than their design windspeed (given in Figure 2-26).

The effects of the many lesser events in Figure 2-26 may be significant in terms of losses, particularly for structural assets covered by homeowners' policies but not designed to the same wind loads for dwellings (such as attached and detached structures). The effect of tree fall from these lesser events may be important contributors to loss costs in parts of Florida.

Non-Hurricane Winds. The wind mitigation insurance rate differentials apply to all windstorms and not just hurricanes. In certain areas in North Florida, non-hurricane winds may contribute significantly to the wind risk. Non-hurricane winds in Florida are dominated by thunderstorm winds and the occasional extra-tropical cyclone.[8] Figure 2-26 indicates that the frequency of hurricane winds less than the design event is also relatively small for some locations (Points 1, 3, and 9) in the north central part of the State.

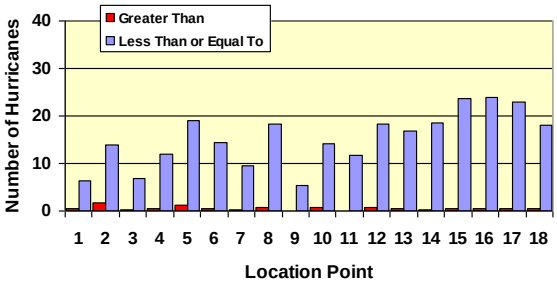


Figure 2-26. Average Number of Hurricanes per 100 Years with Winds Greater Than and Less Than the Design Windspeeds.

To determine the contribution of non-hurricane wind risks, we analyzed four Florida locations:Tallahassee, Jacksonville, Tampa, and Palm Beach. The non-hurricane winds are airport station data from KTLH, KJAX, KTP, and KPBI, respectively. This analysis follows conventional analysis of extreme wind data by fitting the annual extremes to a Type I Distribution. We fitted the data using both method of moments and least squares. We used the hurricane risks from Points 3, 7, 10, and 15, respectively for these 4 locations. Figure 2-27 illustrates how the wind risks compare for hurricane and non-hurricane events. We see that only for Tallahassee are non-hurricane winds (predominately thunderstorm winds) more likely than hurricane winds over the return periods shown in the plot. Hurricane winds cross (become dominant over) the non-hurricane winds at about a 50-year return period for Jacksonville, 10-year return period for Tampa, and 5-year return period for Palm Beach. Clearly, hurricane winds dominate the risks for all of these locations except Tallahassee. The combined risk curve in Figure 2-27 is developed by adding the probabilities of exceedance for hurricanes and non-hurricanes at each return period.

Resource and schedule constraints do not permit consideration of non-hurricane winds, even for locations where hurricanes do not dominate, such as Tallahassee. In this case, we will simply use the hurricane results for those locations with no corrections for non-hurricane winds. Since loss relativities are normalized by location, the fact that non-hurricane winds may be important for a few locations in Florida will not be significant for the remainder of the state. A further issue is that insurance companies often have different deductibles for hurricanes and non-hurricane wind events. These differences could be important for the low-hazard locations where non-hurricane winds dominate the wind hazard.

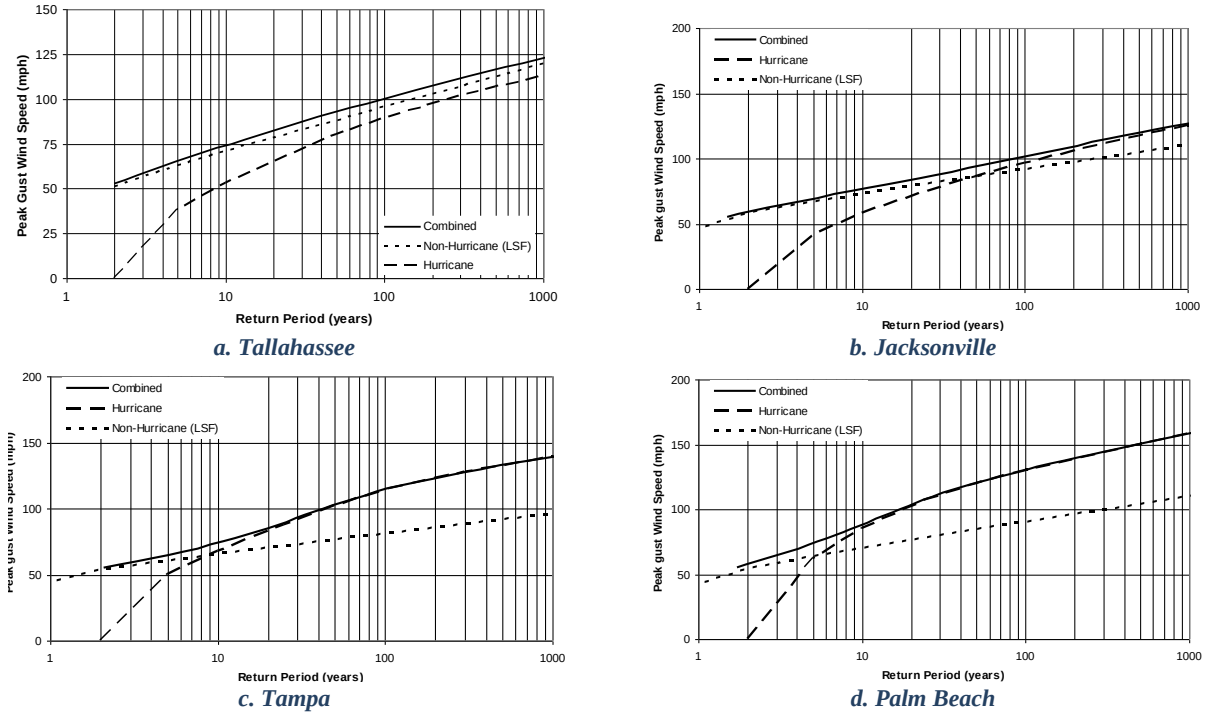
2.4.4 Terrains

Terrain (effects of surface roughness on the upwind fetch) is a fundamental parameter in the design of buildings for wind and must be treated in the analysis of the effectiveness of wind loss mitigation construction features. The key issues were reviewed in Section 2.2.2.

Our approach is to simulate multiple terrains at each point. In 2002, we simulated Terrain B and Terrain C at terrain-specific location points. That is, each point was assumed to have a unique terrain associated with it. There were 17 Terrain B locations and 14 Terrain C locations. In this study we will

[8] At higher return periods (~2,000 to 10,000 years), tornadoes enter the risk profile. We do not consider tornado winds in the above discussion, as they would not become a factor in the loss costs for a building until about the 10,000-year return period events.

simulate multiple terrains (B and C) at each of the 18 Florida locations. The results will be presented in separate tables by terrain, as was done in 2002.



a. Tallahassee *b. Jacksonville*

c. Tampa *d. Palm Beach*

Figure 2-27. Hurricane and Non-Hurricane Winds for Tallahassee.

Schedule and resource constraints have not permitted us to consider additional terrains, such as coastal exposures (Terrain D) or heavily treed exposures, typical of many locations in central and north Florida. In a more refined treatment of coastal terrain, we would consider barrier islands and locations within 600 ft of the coast as Terrain D. Terrain D exposure includes very high wind loads as well as sand and salt spray environments that further damage buildings and escalate losses.

Loss relativities for treed terrain are also notably different than those for Terrains B or C. Research into terrain effects for the Florida Building Commission is producing significant amounts of new data for treed terrain. This work needs to be incorporated into loss relativity analysis to accurately reflect how wind mitigation features perform in treed environments typical of many single family subdivisions in Central and Northern Florida.

We recommend that treed terrain and ASCE Exposure D terrain be incorporated into the loss mitigation relativities.

2.5 Building Models and Groups

Three-dimensional models of buildings are required for the hurricane damage and loss simulations. A computer-aided design (CAD) model is developed that provides a close representation of a real building, including roof geometry, height, plan dimensions, windows, doors, garage doors, and skylights. The resistances of the building components are key inputs to the engineering model of the building. By varying the strength and/or presence of certain components, a measure of the effectiveness of wind mitigation can be quantified for all possible combinations of features on the same building. This approach is then repeated by modeling and analyzing multiple building models to ensure that the results are not just based on one building model or plan geometry. We use the same building models for analyzing existing construction (built prior to FBC 2001) as we do for analyzing FBC construction.

In the 2002 studies, we used straightforward and generally simplified geometries of buildings. Most of the building models had rectangular plans. The simplified geometries provided ease of CAD change-out for roof shape for the same building model and also facilitated computer runs in a reasonable amount of time. For this study, we use both a mixture of simplified geometries of idealized buildings and models of actual buildings. The "real" building models are based on Florida site visits, coupled with drawings and photographs.

The types of residential occupancies considered in this study include single family (SF) and multi-family (MF) residences. As discussed in Section 2.2.3, the *FBC* introduced a separate Residential Code in 2004. *FBC Building* can be used for any residence in Florida whereas *FBC Residential* can only be used in certain cases. We note that the application of the *FBC Residential Code* is limited to 1 or 2 family dwellings, which are 3 stories or less. *FBC Residential* can also be used for townhomes of 3 stories or less, which must have a separate means of egress on the first floor. There is no 30 ft limit in this distinction in the *FBC Residential;* however, some of the prescriptive requirements are limited to building with 30 ft or less mean roof height. For purposes of this study the distinction between *FBC Residential* and FBC Building is not particularly significant for SF residences. We have designed the buildings for which the *FBC Residential* would apply, however we used the prescriptive requirements allowed under the *FBC Residential*, since this is how most homes are built. We compared the *FBC Building* designs to the *FBC Residential* designs and found generally small differences, except that *FBC Residential* requires the use of ring-shank nails.

The construction requirements for residential buildings are governed by the *FBC*. Residential buildings are classified as Occupancy Category II in the ASCE 7 standard and are designed with in Importance Factor of 1.0. This means that the loads are multiplied by the Importance Factor of 1.0 in the determination of the strength factors needed to resist the loads. For structures such as attached screen enclosures, they are currently classified as Occupancy Category I (low hazard to human life in the event of failure) in the ASCE 7. These types of structures have an Importance Factor of 0.77 and hence have an inherent failure rate much higher than the dwelling. As discussed later in this report, such attached and detached structures and any other "non-dwelling" structures have not been considered in this study. Hence the wind mitigation rate differentials developed in this study do not apply to non-dwelling structures that are not treated by the FBC and ASCE 7 as an Occupancy Category II building. For more discussion on losses associated with non-dwelling type structures, Twisdale et. al. (2007) evaluate issues of insurability of attached and detached structures for single family and mobile homes.

The residential building groups used herein follow the requirement of the FBC for SF and MF buildings. Beyond SF and MF groups, we consider differences in the construction characteristics to further subdivide the MF group. Insurance policies generally have a distinction for the buildings with 4 or less families. Hence, the 2002 loss relativity studies included a study for single family houses (ARA, 2002a) and a second study for multi-family residences that have 5 or more units (ARA, 2002b). We understood that insurance companies would generally use the SF report for 1-4 family dwellings and the MF report for 5 or more family dwellings. Insurance companies should apply the SF and MF model building studies herein consistent with their policy language. We note that the construction features of SF and MF buildings three stories and less are very similar and would often fall under *FBC Residential*, as noted above.

Table 2-6 provides a summary of the building models used in this study. These distinct models correspond to different buildings, as well as possible combinations of mitigation features that involve changes in geometry to the building envelope of the same building. For example, number of stories, roof shape, roof slope, garage, and skylights are the envelope parameters that require a modification to a building CAD model. These variations for the same basic building are given in the table. We note that many mitigation features, such as roof deck strength, do not require a separate CAD model since the strength of the roof deck is not a geometry related model change. The strength of the roof deck is changed by modifying specific inputs for a model building and does not require a change to the CAD model.

Table 2-6. Summary Data for Modeled Buildings

Model Index No.	Builiding Group	Building Model	Roof Geometry	Roof Slope	No. of Stories	SF Garage	SF Porch	SF Skylight	Wall Area % Fens	Wall Area % Glazing	Fenstration Count							Total Sq Ft	Livable Sq Ft	Notes
											Window	Door	Slider	Garage Door	Skylight	Total	Leak Potential Count			
1	SF	1304g	Gable	4:12	1	Yes	No	No	26	14	10	2	1	1	0	14	17	1,800	1,316	Simple model. This is model 0013 used in the 2002 studies
2	SF	1304h	Hip	4:12	1	Yes	No	No	26	15	10	2	1	1	0	14	17	1,800	1,316	Simple model. This is model 0013 used in the 2002 studies
3	SF	1307g	Gable	7:12	1	Yes	No	No	22	13	10	2	1	1	0	14	17	1,800	1,316	Simple model. This is model 0013 used in the 2002 studies
4	SF	1307h	Hip	7:12	1	Yes	No	No	26	15	10	2	1	1	0	14	17	1,800	1,316	Simple model. This is model 0013 used in the 2002 studies
5	SF	2304g	Gable	4:12	2	Yes	No	No	16	11	20	2	1	1	0	24	27	3,600	3,116	Simple 2 story model; not used in final production runs.
6	SF	2304h	Hip	4:12	2	Yes	No	No	17	12	20	2	1	1	0	24	27	3,600	3,116	Simple 2 story model; not used in final production runs.
7	SF	2307g	Gable	7:12	2	Yes	No	No	16	11	20	2	1	1	0	24	27	3,600	3,116	Simple 2 story model; not used in final production runs.
8	SF	2307h	Hip	7:12	2	Yes	No	No	17	12	20	2	1	1	0	24	27	3,600	3,116	Simple 2 story model; not used in final production runs.
9	SF	2204G	Gable	4:12	2	Yes	No	No	17	10	15	3	1	1	0	20	23	3,000	2,516	Simple 2 story model, used in previous studies.
10	SF	2204H	Hip	4:12	2	Yes	No	No	18	11	15	3	1	1	0	20	23	3,000	2,516	Simple 2 story model, used in previous studies.
11	SF	2207G	Gable	7:12	2	Yes	No	No	16	10	15	3	1	1	0	20	23	3,000	2,516	Simple 2 story model, used in previous studies.
12	SF	2207H	Hip	7:12	2	Yes	No	No	18	11	15	3	1	1	0	20	23	3,000	2,516	Simple 2 story model, used in previous studies.
13	SF	A103g	Gable	6:12	1	Yes	Yes	No	20	12	9	1	1	1	0	12	15	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
14	SF	A143g	Gable	4:12	1	Yes	Yes	No	18	11	9	1	1	1	0	12	15	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
15	SF	A143h	Hip	4:12	1	Yes	Yes	No	20	12	9	1	1	1	0	12	15	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
16	SF	A173g	Gable	7:12	1	Yes	Yes	No	16	10	9	1	1	1	0	12	15	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
17	SF	A173h	Hip	7:12	1	Yes	Yes	No	20	12	9	1	1	1	0	12	15	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
18	SF	A144g	Gable	4:12	1	Yes	No	No	18	11	9	1	1	1	0	12	15	2,467	1,986	Actual Florida home design; A143g without porch;
19	SF	A144h	Hip	4:12	1	Yes	No	No	20	12	9	1	1	1	0	12	15	2,467	1,986	A143h without porch
20	SF	A174g	Gable	7:12	1	Yes	No	No	16	10	9	1	1	1	0	12	15	2,467	1,986	A173g without porch
21	SF	A174h	Hip	7:12	1	Yes	No	No	20	12	9	1	1	1	0	12	15	2,467	1,986	A173h without porch
22	SF	A175G	Gable	7:12	1	No	No	No	11	10	9	1	1	0	0	11	14	2,467	2,406	Used for no garage Sensitivity Case
23	SF	A176G	Gable	7:12	1	Yes	No	Yes	16	10	9	1	1	1	2	14	17	2,467	1,986	Used for skylight Sensitivity Case
24	SF	A177G	Gable	7:12	1	Yes	No	No	27	20	19	2	3	1	0	25	34	2,467	1,986	Used for increased Fenestration Sensitivity
25	SF	A178G	Gable	7:12	1	Yes	No	No	16	10	8	1	1	1	0	11	14	2,467	1,986	Used for decreased Fenestration Sensitivity
26	SF	K203h	Hip	6:12	2	Yes	No	No	14	11	17	1	1	1	0	20	23	4,233	3,820	Actual Florida Home- 2 story with no porch
27	SF	K243g	Gable	4:12	2	Yes	No	No	13	10	17	1	1	1	0	20	23	4,233	3,820	Actual Florida Home- 2 story with no porch
28	SF	K243h	Hip	4:12	2	Yes	No	No	14	11	17	1	1	1	0	20	23	4,233	3,820	Actual Florida Home- 2 story with no porch
29	SF	K273g	Gable	7:12	2	Yes	No	No	12	9	17	1	1	1	0	20	23	4,233	3,820	Actual Florida Home- 2 story with no porch
30	SF	K273h	Hip	7:12	2	Yes	No	No	14	11	17	1	1	1	0	20	23	4,233	3,820	Actual Florida Home- 2 story with no porch
31	MF-I	0024F	Flat	0:12	2				18	15	64	16	16	0	0	96	144	14,592	14,592	Simple plan; large Group I model used in the 2002 study
32	MF-I	0024G	Gable	4:12	2				21	17	64	16	16	0	0	96	144	14,592	14,592	Simple plan; large Group I model used in the 2002 study
33	MF-I	0024H	Hip	4:12	2				21	18	64	16	16	0	0	96	144	14,592	14,592	Simple plan; large Group I model used in the 2002 study
34	MF-I	0027G	Gable	7:12	2				20	17	64	16	16	0	0	96	144	14,592	14,592	Simple plan; large Group I model used in the 2002 study
35	MF-I	0027H	Hip	7:12	2				21	18	64	16	16	0	0	96	144	14,592	14,592	Simple plan; large Group I model used in the 2002 study
36	MF-I	S301F	Flat	0:12	3				24	21	90	24	36	0	0	150	258	35,160	35,160	Actual Fliorida Building- Group I
37	MF-I	S341G	Gable	4:12	3				22	19	90	24	36	0	0	150	258	35,160	35,160	Actual Fliorida Building- Group I
38	MF-I	S341H	Hip	4:12	3				23	20	90	24	36	0	0	150	258	35,160	35,160	Actual Fliorida Building- Group I
39	MF-I	S371G	Gable	7:12	3				20	18	90	24	36	0	0	150	258	35,160	35,160	Actual Fliorida Building- Group I
40	MF-I	S371H	Hip	7:12	3				22	19	90	24	36	0	0	150	258	35,160	35,160	Actual Fliorida Building- Group I
41	MF-II	0057F	Flat	0:12	5				24	24	115	0	80	0	0	195	435	33,600	33,600	Simple plan; Group II model used in 2002 study
42	MF-II	WW31F	Flat	0:12	3				14	12	99	18	0	0	0	117	117	28,620	28,620	Actual Florida Building-Group II
43	MF-III	0087F	Flat	0:12	8				24	24	184	0	128	0	0	312	696	53,760	53,760	Simple plan; Group III model used in 2002 study
44	MF-III	SB31F	Flat	0:12	10				28	28	90	0	360	0	0	450	1530	240,000	240,000	Actual Florida Building-Group Iii

Hence, the mitigation effectiveness of most mitigation features can be evaluated using a single CAD model of the building. By varying mitigation features on the same building model coupled with using multiple building models, we can evaluate mitigation effectiveness "within and across" building models.

The data in Table 2-6 are grouped by building type, according to:

1. Single Family (SF)
2. Multi-Family (MF)
    a. Group I (MF-I)
    b. Group II (MF-II)
    c. Group III (MF-III)

Due to considerations of computer run time, we have simplified the number of different buildings within the SF and MF groups for this study. Each group has two basic building plans with geometrical CAD variations as needed. The discussion of the SF and MF groups are given in Sections 2.5.1 and 2.5.2. The estimated building values for these modeled buildings are summarized in Section 3.

2.5.1 Single-Family Residences

The SF models correspond to index numbers 1-30 in Table 2-6. There are four basic SF models used in the final runs of this study: 2 single-story and 2 two-story residences. Model index numbers 1-4 correspond to the simple single story rectangular floor plan and numbers 9-12 correspond to the simple two story rectangular floor plan. The livable areas are about 1300 sf for the simple one story and 2,500 sf for the simple two story homes. The number of windows and doors for these buildings are typical of average construction cost class. These simple rectangular plans were used in the 2002 study and hence provide a consistent benchmark for checks of new results vs. previous 2002 results.

Model numbers 18-25 correspond to an actual Florida one-story single family home with a more complex floor plan typical of more recent construction. This home has about 1900 sf of livable space. This house has a built-in garage, as does all the basic SF models used herein. We choose to use this house for several sensitivity studies. Variations in the CAD model for this house for sensitivity analysis are given in rows 22-25, which correspond respectively to: 22, no garage (garage replaced by livable space; 23, skylights added; 24, increased number of windows and doors; and 25, decreased number of window and doors.

Model numbers 37-30 correspond to an actual Florida two-story single family home. While this home has a rectangular floor plan, it is larger than the simple model and includes a small roof cover over the entrance way. This house has about 3,800 sf of livable space.

Photos of an *FBC* houses under construction are given in Figure 2-28. Roof-to-wall, window framing, and wall-to-floor plate connections are illustrated for a post-FBC home. Figure 2-29 shows construction photos of another Florida house. The soffit blocking is illustrated as well as the substantial number of connectors in the roof-to-wall areas.

CAD views of the basic SF buildings are given in Figure 2-30. A complete set of CAD views of all the buildings is given in Appendix C. The "G", "H", or "F" on the CAD number denotes the roof shape as gable, hip, and flat respectively.



Figure 2-28. Framing and Connection Details for Post-FBC Gable Roof Home.



Figure 2-29. One-Story Hip Roof Post-FBC Home.

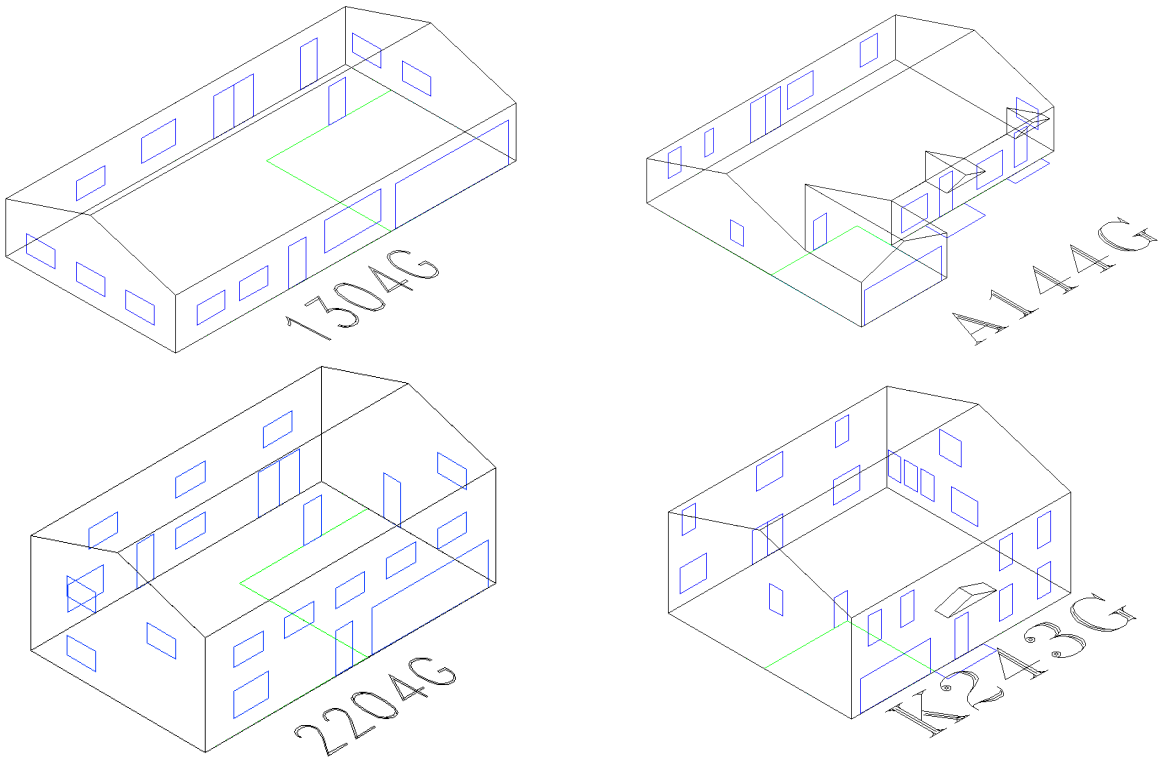


Figure 2-30. Basic Geometries of Single Family Building Models.

2.5.2 Multi-Family

Multi-family residences include a wide range of building types and number of residential units within the building. As discussed previously, small lowrise buildings are often built to the same requirements as a single-family home, where large high rise condominium buildings are built to the *FBC Building*. Small lowrise buildings generally have wood or masonry frames, whereas large buildings often have reinforced concrete or structural steel frames. Highrise buildings generally have a reinforced concrete roof deck, whereas small lowrise buildings often have a wood roof deck.

In this study, we use the same groups for multi-family building types as was done in the 2002 study (ARA, 2002b). The first group of buildings includes lowrise, buildings, typically one to three stories in height, constructed with either wood or masonry walls and having a wood rafter or truss roof system and wood roof deck. The construction characteristics of the Group I Buildings are similar to that of single family residential buildings. Group I Buildings include gable, hip and flat roof shapes.

The second group of buildings consists of multi-story buildings less than sixty feet tall, in which the structural system is designed by an engineer. These Group II buildings are usually constructed from steel or concrete, with either steel or concrete roof decks.[9] Low-rise (1-4 stories), flat-roofed buildings with concrete roof decks should be treated as Group II as opposed to Group I.

The third group of buildings consists of buildings over sixty feet in height. For buildings over sixty feet tall, the design of the building and its components has generally been developed using ASCE 7 instead of SBC. The use of ASCE-7 predicts designs that must withstand higher wind loads.

[9] Engineered Group II Buildings that have wood roof decks should be considered as Group I buildings for purposes of loss mitigation relativity determination.

Table 2-7 summarizes these three building height groups. This categorization by building height is by predominant construction and design methods that have existed in the building codes. The user should select the appropriate group based on frame construction and building height. For example, a four-story wood frame building should be classified using the parameters in Group I (although Group I typically applies to less than three-story buildings). All buildings over 60 feet in height should be classified by Group III regardless of the typical construction. The Model Building Height column in Table 2-3 refers to the actual height of the modeled buildings used in the study. A simplified decision tree is illustrated in Figure 2-31 in which roof deck material distinguishes Group I from Group II buildings. This simplified approach should help avoid misclassifications of multi-family residences.

Table 2-7. Building Construction Groups for Condominium and Tenant Buildings

Group	*Typical Frame Construction*	*Typical Roof Deck Material*	*Typical Heights*	*Model Building Heights*
I	Masonry or Wood Frame	Wood	1-4 stories	2, 3 stories
II	Steel, or Reinforced Concrete, or Reinforced Masonry	Concrete or Steel	≤60 feet	3, 5 stories
III	Steel or Reinforced Concrete	Concrete or Steel	>60 feet	8, 10 stories

Group I Buildings. Models of Group I Buildings have been developed that consist of two geometries and 3 roof shapes (hip, gable and flat). The rectangular plan has about 15,000 square feet and includes model numbers 31-35 in Table 2-6. There are 2 roof slopes (4:12 and 7:12) for the gable and hip versions, producing a total of 5 CAD models.

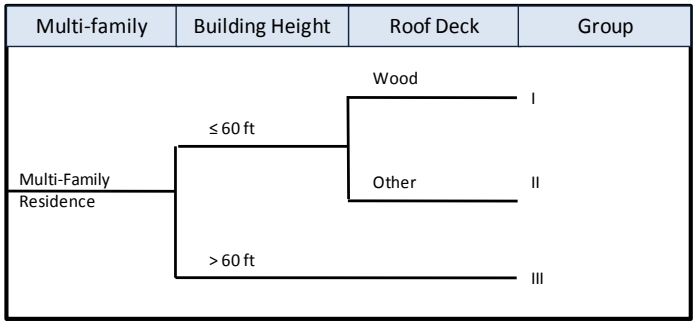
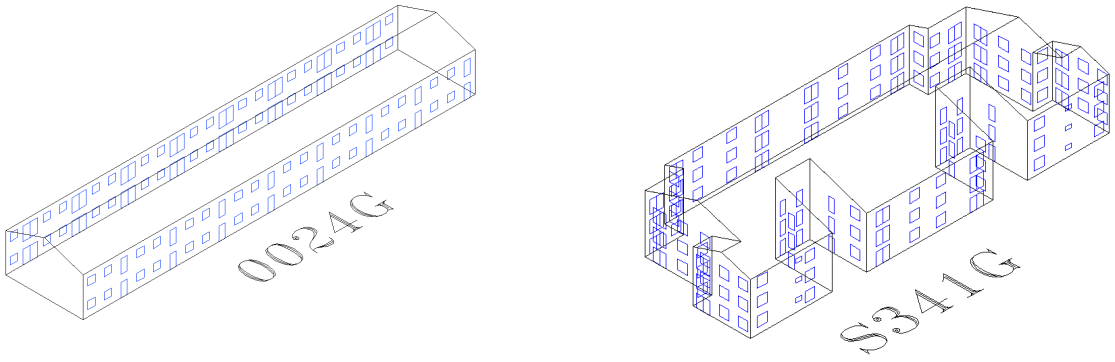


Figure 2-31. Classification Decision Tree for Multi-family Group I, II, and III Residences.

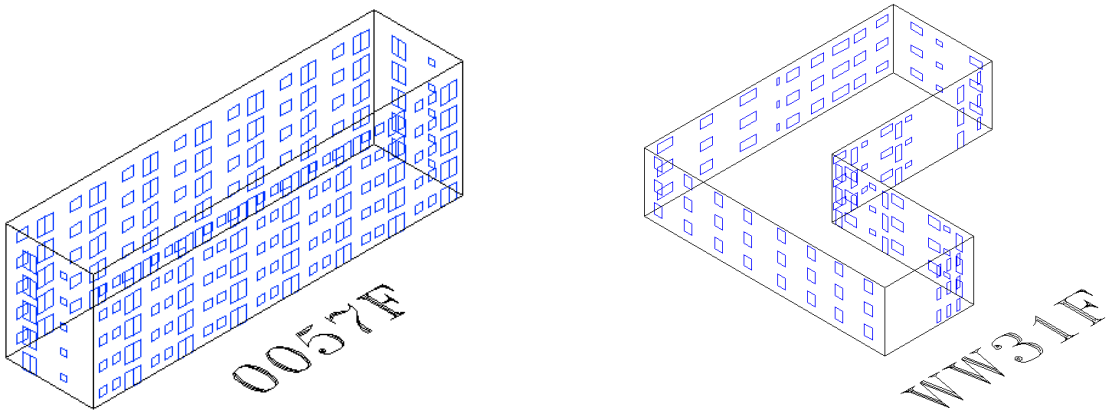
Model numbers 36-40 are for an actual Florida building with a more complex plan. This is also a larger building with about 35,000 square feet. This building has also been developed with three roof shapes. We note that the introduction of the flat roof case yields a feature of Group I buildings not considered in the 2002 multi-family residential loss relativity study (flat and gable roof buildings were grouped into one class and modeled as a gable).

Figure 2-32 shows the basic geometries of the MF building models. Appendix C provides a complete set of CAD views.

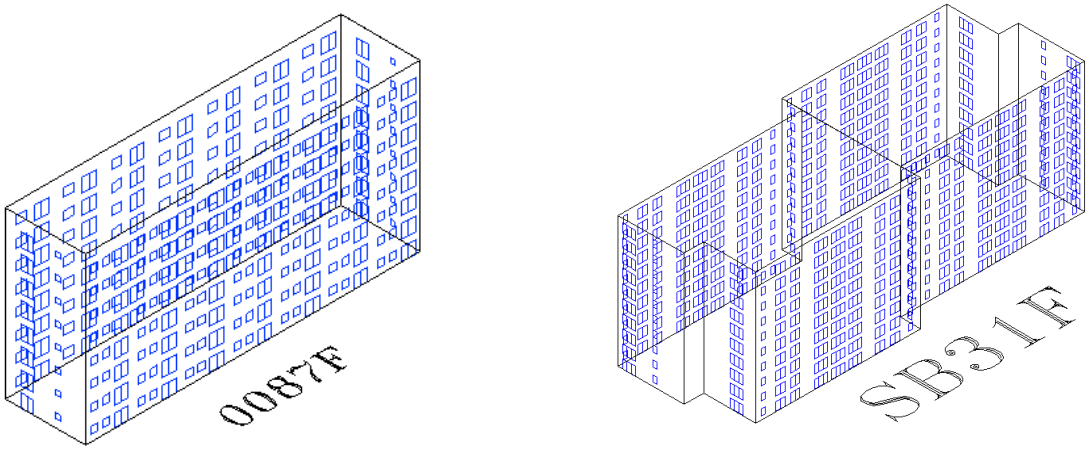
Group II and III Buildings. All the Group II and III models have flat roof shapes. There are two models each for the Group II and Group III Buildings. Models 41 and 43 are the same Group II and Group III model buildings used in the 2002 loss relativity study. Models 42 and 44 are actual Florida buildings. Model 44 is a much larger building (240,000 square feet) than any other model in the study. This building is typical of many large condominium buildings in Florida.



a. Group I Buildings



b. Group II Buildings



c. Group III Buildings

Figure 2-32. Basic Geometries of MF Buildings.

2.5.3 Replacement Cost Estimates

Table 2-8 provides estimated replacement cost values for single family homes. These values were estimated using 2008 RS Means Residential Cost Data (RS Means 2008a). This reference provides construction costs for single family homes based on their construction cost class and the number of stories. The replacement values compiled for this study correspond to the Average Construction Cost

Class for a location in the Fort Lauderdale/West Palm Beach area for 1 and two story homes. This area was chosen as the basis for the cost estimation because it has a location adjustment factor in the RS Means data that is approximately equal to the state-wide average. The replacement costs range from about $65 to $82 per square foot for the options considered. In addition to the base costs from RS Means, the reference was used to adjust for garages, wall framing type, roof cover type, roof slope, and the number of windows, doors and skylights.

Table 2-8. Replacement Cost Estimates for SF Building Models

Model Index No.	Builiding Group	Building Model	Roof Geometry	Roof Slope	No. of Stories	SF Garage	SF Porch	SF Skylight	Total Fens	Total Sq Ft	Livable Sq Ft	Replacement Cost Values ($)			
												Masonry-Shingle Roof	Masonry - Tile Roof	Frame-Shingle Roof	Frame - Tile Roof
1	SF	1304g	Gable	4:12	1	Yes	No	No	14	1,800	1,316	$ 119,846	$ 129,949	$ 116,203	$ 126,306
2	SF	1304h	Hip	4:12	1	Yes	No	No	14	1,800	1,316	$ 120,807	$ 133,537	$ 117,164	$ 129,894
3	SF	1307g	Gable	7:12	1	Yes	No	No	14	1,800	1,316	$ 120,534	$ 132,518	$ 116,891	$ 128,875
4	SF	1307h	Hip	7:12	1	Yes	No	No	14	1,800	1,316	$ 121,674	$ 136,773	$ 118,032	$ 133,130
5	SF	2304g	Gable	4:12	2	Yes	No	No	24	3,600	3,116	$ 261,153	$ 272,771	$ 249,722	$ 261,340
6	SF	2304h	Hip	4:12	2	Yes	No	No	24	3,600	3,116	$ 262,258	$ 276,897	$ 250,828	$ 265,466
7	SF	2307g	Gable	7:12	2	Yes	No	No	24	3,600	3,116	$ 261,944	$ 275,725	$ 250,514	$ 264,294
8	SF	2307h	Hip	7:12	2	Yes	No	No	24	3,600	3,116	$ 263,255	$ 280,619	$ 251,825	$ 269,188
9	SF	2204G	Gable	4:12	2	Yes	No	No	20	3,000	2,516	$ 213,904	$ 223,585	$ 204,674	$ 214,355
10	SF	2204H	Hip	4:12	2	Yes	No	No	20	3,000	2,516	$ 214,825	$ 227,023	$ 205,595	$ 217,794
11	SF	2207G	Gable	7:12	2	Yes	No	No	20	3,000	2,516	$ 214,563	$ 226,047	$ 205,334	$ 216,818
12	SF	2207H	Hip	7:12	2	Yes	No	No	20	3,000	2,516	$ 215,656	$ 230,126	$ 206,426	$ 220,896
13	SF	A103g	Gable	6:12	1	Yes	Yes	No	12	2,657	1,986	$ 173,795	$ 190,877	$ 168,297	$ 185,379
14	SF	A143g	Gable	4:12	1	Yes	Yes	No	12	2,657	1,986	$ 173,001	$ 187,913	$ 167,503	$ 182,415
15	SF	A143h	Hip	4:12	1	Yes	Yes	No	12	2,657	1,986	$ 174,419	$ 193,208	$ 168,921	$ 187,711
16	SF	A173g	Gable	7:12	1	Yes	Yes	No	12	2,657	1,986	$ 174,016	$ 191,704	$ 168,519	$ 186,207
17	SF	A173h	Hip	7:12	1	Yes	Yes	No	12	2,657	1,986	$ 175,699	$ 197,986	$ 170,201	$ 192,488
18	SF	A144g	Gable	4:12	1	Yes	No	No	12	2,467	1,986	$ 172,610	$ 186,456	$ 167,113	$ 180,958
19	SF	A144h	Hip	4:12	1	Yes	No	No	12	2,467	1,986	$ 173,928	$ 191,373	$ 168,430	$ 185,875
20	SF	A174g	Gable	7:12	1	Yes	No	No	12	2,467	1,986	$ 173,554	$ 189,977	$ 168,056	$ 184,479
21	SF	A174h	Hip	7:12	1	Yes	No	No	12	2,467	1,986	$ 175,116	$ 195,810	$ 169,618	$ 190,312
22	SF	A175G	Gable	7:12	1	No	No	No	11	2,467	2,406	$ 190,569	$ 206,992	$ 183,909	$ 200,332
23	SF	A176G	Gable	7:12	1	Yes	No	Yes	14	2,467	1,986	$ 174,455	$ 190,879	$ 168,958	$ 185,381
24	SF	A177G	Gable	7:12	1	Yes	No	No	25	2,467	1,986	$ 178,419	$ 194,843	$ 172,921	$ 189,345
25	SF	A178G	Gable	7:12	1	Yes	No	No	11	2,467	1,986	$ 173,067	$ 189,491	$ 167,569	$ 183,993
26	SF	K203h	Hip	6:12	2	Yes	No	No	20	4,233	3,820	$ 318,780	$ 338,651	$ 304,767	$ 324,638
27	SF	K243g	Gable	4:12	2	Yes	No	No	20	4,233	3,820	$ 316,547	$ 330,314	$ 302,534	$ 316,301
28	SF	K243h	Hip	4:12	2	Yes	No	No	20	4,233	3,820	$ 317,856	$ 335,203	$ 303,843	$ 321,190
29	SF	K273g	Gable	7:12	2	Yes	No	No	20	4,233	3,820	$ 317,484	$ 333,814	$ 303,471	$ 319,801
30	SF	K273h	Hip	7:12	2	Yes	No	No	20	4,233	3,820	$ 319,038	$ 339,614	$ 305,025	$ 325,601

Table 2-9 provides the replacements costs used in the analysis for multi-family buildings. These costs were developed following a similar method to that used for single family homes, however the source of the cost data was RS Means 2008 Square Foot Costs (RS Means 2008b). This reference provides costs for a broad range of commercial style construction. The base models used for creating the multi-family housing costs were the basic "Apartment, 1-3 Story", "Apartment, 4-7 Story", and "Apartment, 8-24 Story". The costs used correspond to the Average Construction Cost Class for a location in the Fort Lauderdale/West Palm Beach area and range from about $120 to $190 per square foot.

Table 2-9. Replacement Cost Estimates for MF Building Models.

Model Index No.	Builiding Group	Building Model	Roof Geometry	Roof Slope	No. of Stories	SF Garage	SF Porch	SF Skylight	Total Fens	Total Sq Ft	Livable Sq Ft	Replacement Costs($)		
												Shingle	Tile	Built-up Roof
31	MF-I	0024F	Flat	0:12	2				96	14,592	14,592			$ 1,934,136
32	MF-I	0024G	Gable	4:12	2				96	14,592	14,592	$ 1,903,034	$ 1,942,276	
33	MF-I	0024H	Hip	4:12	2				96	14,592	14,592	$ 1,906,767	$ 1,956,212	
34	MF-I	0027G	Gable	7:12	2				96	14,592	14,592	$ 1,905,707	$ 1,952,254	
35	MF-I	0027H	Hip	7:12	2				96	14,592	14,592	$ 1,910,135	$ 1,968,784	
36	MF-I	S301F	Flat	0:12	3				150	35,160	35,160			$ 4,221,969
37	MF-I	S341G	Gable	4:12	3				150	35,160	35,160	$ 4,172,011	$ 4,235,048	
38	MF-I	S341H	Hip	4:12	3				150	35,160	35,160	$ 4,178,008	$ 4,257,435	
39	MF-I	S371G	Gable	7:12	3				150	35,160	35,160	$ 4,176,305	$ 4,251,077	
40	MF-I	S371H	Hip	7:12	3				150	35,160	35,160	$ 4,183,418	$ 4,277,631	
41	MF-II	0057F	Flat	0:12	5				195	33,600	33,600			$ 4,499,522
42	MF-II	WW31F	Flat	0:12	3				117	28,620	28,620			$ 3,862,717
43	MF-III	0087F	Flat	0:12	8				312	53,760	53,760			$ 10,178,414
44	MF-III	SB31F	Flat	0:12	10				450	240,000	240,000			$ 36,276,659

2.6 Loss Simulation Approach Using the HURLOSS Model

ARA's hurricane loss model, HURLOSS, is summarized in the public domain submittal to the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM). The model was first accepted by the Commission under the 1999 Standards and has been reviewed and accepted each year since the 1999 submission. An updated version of the HURLOSS model is used in this study to produce loss costs relativities. The specific updates developed for this study are presented in Section 3.6.

HURLOSS has been developed using wind engineering principles to enable detailed estimates of damage and loss to buildings and their contents due to wind storms. The model uses a peer reviewed hurricane hazard model that enables the modeling of the entire track of a hurricane or tropical storm. The hurricane windfield model has been extensively validated against surface level windspeed, wind direction, and atmospheric pressure observations. The results of ARA's hurricane hazard model were used directly in the design windspeed map given in the American Society of Civil Engineers Standard 7-98: *Minimum Design Loads for Buildings and Other Structures*. Since the hurricane model simulates the entire hurricane track, whether the storm makes landfall or not, computation of loss does not require that a storm make landfall, but simply requires that the windspeed produced by the storm at any point exceed a predefined minimum value. The model has the ability to treat storms that make multiple landfalls.

ARA's physical damage model is based on load and resistance analysis of building components. The physical damage model estimates the damage to the building in terms of failure of building envelope components. Insured loss is estimated from the building damage states using cost estimation techniques for building repair and replacement. Contents loss is based on an empirical model that relates contents damage to building envelope performance. The building, appurtenant structures, contents, and loss of use components have been validated with insurance loss data. For portfolio assessments, a fast-running loss function is developed for each building class. These functions are used to estimate losses for each coverage type and deductible in each simulated storm.

The computational procedure used in this study is stratified Monte Carlo simulation. The model can produce losses by coverage, policy, site, zip code, county, state, and portfolio levels. The storm-by-storm and year-by-year output data can be post-processed to obtain average annual loss (AAL), as well as the loss distribution statistics (Probable Maximum Loss, etc.) on a per occurrence or per year basis.

Loss costs are not reported in this study since each insurer must perform those calculations for its book of business. The relativities produced herein show how loss costs are expected to vary according to wind resistive features, building code, location, and terrain. The following paragraphs provide further details on the HURLOSS methodology.

2.6.1 Hurricane Hazard Model

Section 2.3 describes the new research on the hurricane wind model. This section summarizes the wind model implementation in HURLOSS. The two key components of the hurricane hazard model are: (i) probabilistic models describing the occurrence rates, storm tracks, and intensities, and (ii) the hurricane windfield model. The probabilistic portion of the hurricane hazard model is described in detail in Vickery, et al. (2000b). The key features of the storm track model are the coupling of central pressure with sea surface temperature and the ability to model curved tracks that can make multiple landfalls. The entire track of a storm is modeled, from the time of storm initiation over the water, until the storm dissipates. The starting times (hour, day, and month) and locations of the storms are taken directly from the Atlantic basin hurricane database (HURDAT). Using the actual starting times and locations ensures that any climatological preference for storms to initiate in different parts of the Atlantic Basin at different times of the year is maintained.

The coupling of the central pressure modeling to sea surface temperature ensures that intense storms (such as category 5 storms) cannot occur in regions in which they physically could not exist (such as the New England area) and, as shown in Vickery, et al. (2000b), the approach reproduces the variation in the central pressure characteristics along the United States coastline. In the hurricane hazard model, the storm's intensity is modeled as a function of sea surface temperature until the storm makes landfall. At the time of landfall, the filling models described in Vickery (2005) are used to model the intensity of the weakening storm. Over land, following the approach outlined in Vickery, et al. (2000b), the storm size is modeled as a function of central pressure and latitude. If the storm exits land into the water, the storm intensity is again modeled as a function of sea surface temperature, allowing the storm to possibly re-intensify and make landfall again elsewhere.

2.6.2 Hurricane Windfield Model

The hurricane windfield model used in HURLOSS is an updated version of that described in detail in Vickery, et al. (2000a). The model uses the results of the numerical solution of the equations of motion of a translating hurricane. The asymmetries in a moving storm are a function of the translation speed of the storm and the nonlinear interactions between the wind velocity vectors and the frictional effects of the surface of the earth. The numerical solutions of the equations of motion of the hurricane have been solved separately for a storm translating over the ocean and for a storm translating over land. The separate solutions were developed for the over land case and the over water case, since in the over water case, the magnitude of the surface drag coefficient is a function of the windspeed itself, whereas in the over land case the magnitude of the surface drag coefficient is windspeed independent. The outputs of the numerical model represent the integrated boundary layer averaged windspeeds, representative of a long duration average wind, taken as having an averaging time of one hour. The mean, one hour average, integrated windspeeds are then combined with a boundary layer model to produce estimates of windspeeds for any height and averaging time.

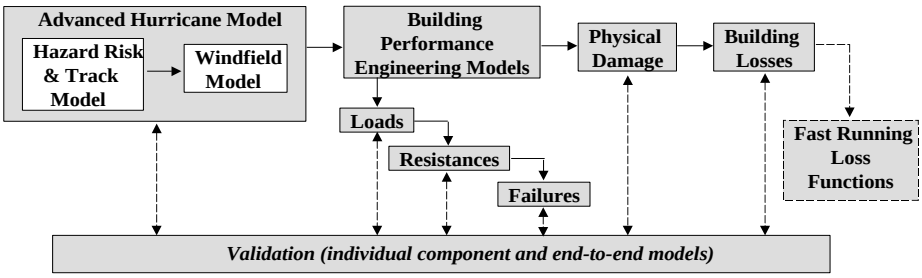
The boundary layer model, described in Vickery, et al. (2008a) and Vickery and Skerlj (2005), is based primarily on the ESDU (1982, 1983) models for the atmospheric boundary layer. The boundary layer model can deal with arbitrary terrain conditions (any surface roughness) changing both the properties of the mean flow field (i.e., the mean windspeed at a given height decreases with increasing surface roughness), as well as the gustiness of the wind (i.e., the gust factor increases with increasing surface roughness). The gust factor portion of the ESDU-based model has been validated through comparisons to gust factors derived from hurricane windspeed traces, as described in Vickery and Skerlj (2005).

As described in Section 2.3, the entire hurricane windfield model (overall flow field, boundary layer model and gust factor model) has been validated through comparisons of simulated and observed windspeeds. These windspeed comparisons have been performed through comparisons of both the peak gust windspeeds and the average windspeeds. The comparisons have shown the windfield model reproduces observed windspeeds well, matching both the gusts and the long period average winds. The model has been validated separately at offshore, coastal and inland stations, taking into account the effects of local terrain and anemometer height on the measured and simulated windspeeds.

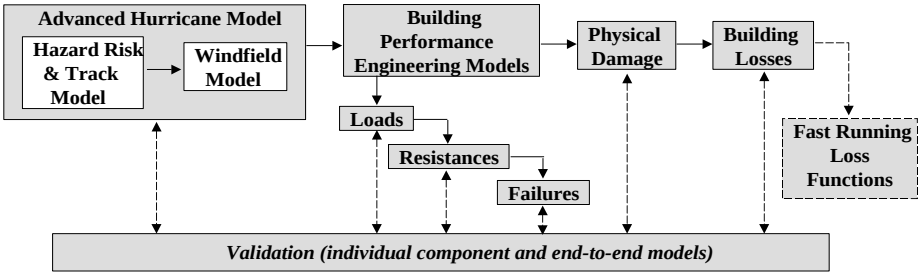
2.6.3 Damage and Loss Model

ARA's modeling approach for damage and loss employs two separate models. A building performance model, using engineering-based load and resistance models, is used to quantify physical damage. The building physical damage model takes into account the effects of wind direction changes, progressive damage, and storm duration. Economic loss, given physical damage, is estimated using repair and reconstruction cost estimation methods. This process is therefore similar to how an insurance adjuster would estimate the claim, given observed damage to the building. Through direct simulations of thousands of storms with representative buildings, the building performance model produces outputs that

are post-processed into loss functions for building, contents, and loss of use. The damage and loss modeling methodology is shown schematically in Figure 2-33. The individual building model approach shown in Figure 2-33a has been used in this study.



(a) Individual Buildings and Building Class Performance Model



(b) Multiple Site – Multiple Building Loss Projections

Figure 2-33. Overview of Hurricane Damage and Loss Modeling.

The HURLOSS modeling approach is based on a load and resistance approach which has been validated and verified using both experimental and field data. The model includes the effects of both wind-induced pressures and wind-borne debris on the performance of a structure in a hurricane. The wind loading models replicate the variation of wind loads as a function of direction, and when coupled with a simulated hurricane windspeed trace, a time history of wind loads acting on the building is produced. The wind loading model has been validated through comparisons with wind tunnel data. The time history of wind loads is used in the damage model to account for the progressive damage that often takes place during a hurricane event. The model also allows the effects of nearby buildings and their impact on the loads acting on the exterior of the structure.

Both the physical damage model and the loss model developed by ARA have been validated through comparisons of modeled and observed damage data collected after hurricane events. Separate models have been developed to estimate the financial losses to the building, the building's contents, additional living expenses, and losses to appurtenant and exterior structures.

The wind resistive features of each building are established for each simulation run of 500,000 years of hurricanes. This is accomplished in the HURLOSS individual risk model by an input file that specifies component and building specifications for each key feature. For example, the roof deck may be specified as ½" plywood with 8d (2½") nails at 12" spacing in the field and 6" spacing on the plywood edge. HURLOSS lays out the roof deck (see Figure 2-34) and computes the resistances based

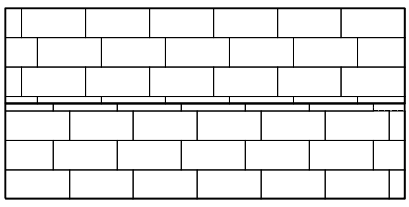


Figure 2-34. Roof Deck Sheathing Layout for House Model SF-A (0011G).

on the nail size and spacing. For this example, the resistances are computed using probabilistic models developed from nail pull-out tests. Similarly, if the roof-to-wall connection is 3-16d (3½") toe nails, HURLOSS models the uplift resistance of that connection. Hence, each house is modeled with strengths that reflect the specified ultimate wind resistance features for that building.

At each time step during a simulated storm, the computed wind loads acting on the building and its components are compared to the modeled resistances of the various components. If the computed wind load exceeds the resistance of the component, the component fails. When a component suchas a window or a door fails, the wind-induced pressure acting on the exterior of the component is transmitted to the interior of the building. This internal pressure is then added (or subtracted) from the wind loads acting on the exterior of the building to determine if any additional components have been overloaded because of the additional loads produced by the internal pressurization of the building.

The progressive failure damage modeling approach is summarized in Figure 2-35. Estimates of wind loads as a function of wind direction are produced for building components, including roof cover, roof sheathing, windows and doors, as well as for larger components including the entire roof, walls and overturning or sliding of the entire building in cases where a positive attachment to the ground does not exist. The statistical properties of the resistances of the building components are obtained from laboratory tests and/or engineering calculations. In the simulation process, the resistances of the individual building components that will be loaded are sampled prior to the simulation of a hurricane, and are held constant throughout the simulation.

The model computes a complete history of the failure of the building, which can be used to make a "movie" of the building performance. Figure 2-36 presents 6 frames from such a movie. The movie in this case represents one realization of a simulation of the expected performance of a house built with hurricane straps, but otherwise satisfying only the minimum criteria of the building code requirements required prior to introduction of the new FBC. The frames show the progressive damage to the building during the passage of the storm caused by a combination changes in wind loads resulting from combination of wind direction and windspeed changes as well as the effects of internal pressurization. Internal pressurization, in this simulation, begins with the first window failure that occurs at just after the windspeed reaches 138 mph (peak gust windspeed).

Once the building damage has been computed for a given storm and the losses for all coverages computed, the process is repeated for a new set of sampled building component resistances. Once a large number of simulations have been performed, we have derived the data necessary to develop a statistical model for the expected performance of the building given the occurrence of a storm.

With this explicit modeling approach, it is possible to assess the impact of the Florida Building Code on the reduction in physical damage and insured loss. For example, the analysis of enclosed designs (protected openings) can be explicitly modeled in the same manner an engineer designs the truss package or the builder selects the windows to comply with the required dynamic pressure rating.

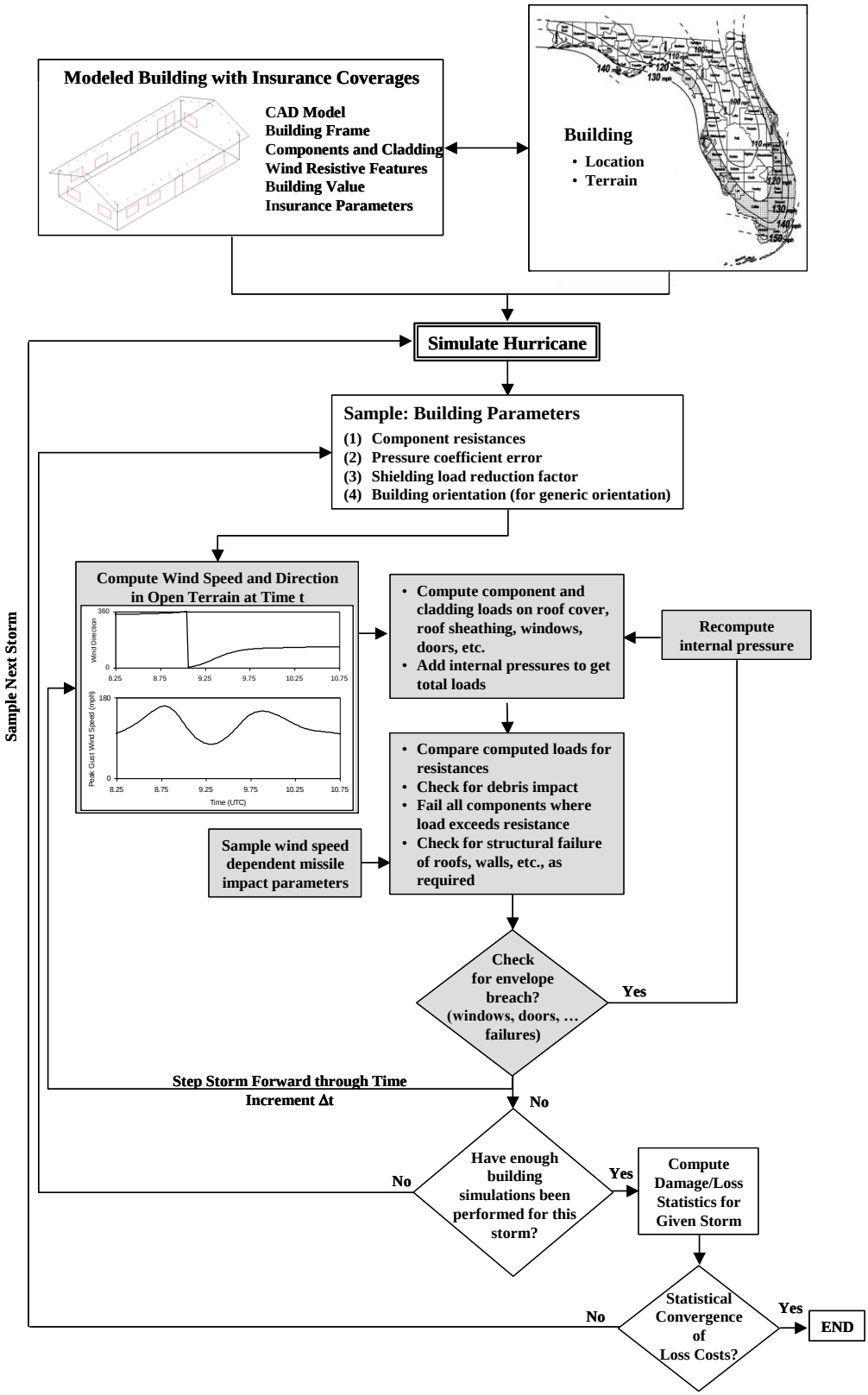


Figure 2-35. HURLOSS Building Damage Simulation Methodology.

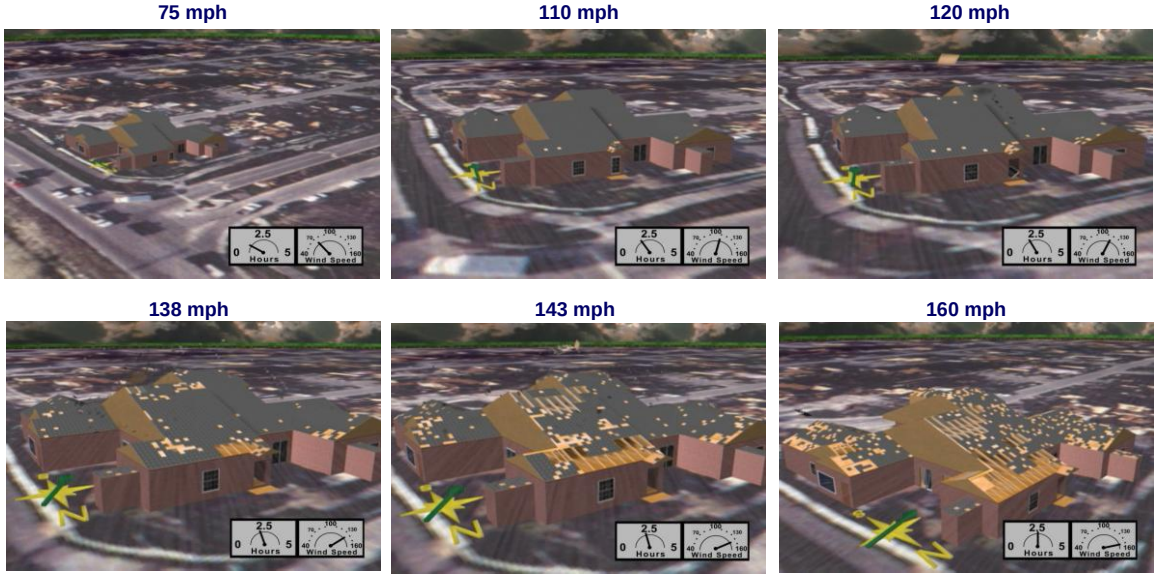


Figure 2-36. Progressive Damage of a Building Modeled using HURLOSS.

2.6.4 HURLOSS Model Summary

The load and resistance modeling approach inherent in the HURLOSS methodology is the only means to reliably ascertain the impact of the change in one building parameter (e.g., roof slope or roof shape) on loss costs. The HURLOSS load and resistance methodology has been extensively validated through comparisons of modeled and observed physical damage to buildings as well as through modeled and observed loss data. The modeling approach is built on the premise that building geometry and local surroundings drive the aerodynamics, wind loads, and wind borne debris, and the resistance of the various building components drives the performance of the building given these loads. The building components also affect the costs of re-construction given damage to the building (e.g., replacement cost of tiles vs. shingles). Given the physical damage to the building, the losses are driven by the costs of replacing components and contents damaged by wind, wind borne debris and wind driven rain. A change in building geometry (number of stories, roof shape, roof slope, etc.), building component type, or resistance (e.g., toe-nail vs. strap roof-wall connection, addition of window protection) will change how the building performs in a hurricane. The physics-based load and resistance modeling approach implemented in HURLOSS allows for these changes in building characteristics to be properly modeled without the need for subjective factors to be applied to losses generated from generic wind-speed vs. damage curves.

2.7 Insurance Assumptions

The insurance parameters used in this study are based on a review of the exposure dataset compiled by the Florida Hurricane Catastrophe Fund (FHCF) for their 2008 ratemaking studies. Our goal is to select a set of insurance parameters that are most representative of Florida windstorm insurance policies for residential, site-built properties. The specific insurance parameters examined are the deductible amounts and the coverage ratios.

2.7.1 Deductibles

Table 2-10 summarizes the distribution of building coverages for residential policies (i.e., owner occupied, 1-4 unit residential properties) as a function of deductible group and year built group. For

residential type of business (TOB), 85% of the statewide aggregate building coverage has a windstorm deductible of 2%. Thus, we will use 2% as the default deductible for the residential relativities.

Table 2-10. Building Coverage Distribution by Deductible Group and Year Built for Residential (1-4 Units) Policies.

	Year Built					
Deductible Group	**1994 or earlier**	**1995-2001**	**2002 or later**	**Unknown**	**Total ($)**	**Total (%)**
1%	3,313,617,919	1,299,619,508	1,261,358,856	489,117,854	6,363,714,137	0.6%
2%	548,727,520,912	168,729,493,327	210,000,416,770	6,362,110,271	933,819,541,278	85.0%
3%	707,408,315	165,169,546	263,997,716	222,454,672	1,359,030,249	0.1%
4%	720,766,171	310,582,911	210,735,428	107,825	1,242,192,335	0.1%
5%	53,004,493,329	15,191,673,361	12,912,411,897	275,411,783	81,383,990,370	7.4%
6%	-	-	-	2,738,755	2,738,755	0.0%
10% to 14% (rate as 10%)	5,276,457,053	1,911,940,004	2,023,442,390	6,595,826	9,218,435,272	0.8%
15% or Greater (rate as 15%)	1,095,674,750	828,527,995	681,193,927	212,244,689	2,817,641,361	0.3%
$0	329,150	709,375	719,590	1,598,801	3,356,916	0.0%
$1 to $500 (rate as $500)	20,852,757,081	5,303,803,881	11,284,160,587	14,664,543,959	52,105,265,507	4.7%
$501 to $1,500 (rate as $1,000)	2,678,914,192	598,124,987	849,106,700	4,721,463,653	8,847,609,532	0.8%
$1,501 to $2,500 (rate as $2,000)	369,165,767	98,380,556	86,644,815	115,535,132	669,726,270	0.1%
Greater Than $2,500 (rate as $3,000)	334,637,362	311,844,815	214,318,621	412,629,569	1,273,430,367	0.1%
Totals	637,081,742,000	194,749,870,265	239,788,507,297	27,486,552,787	1,099,106,672,349	100.0%

For condominium unit owner policies and tenant policies, the primary coverage is usually taken to be the contents coverage. Table 2-11 summarizes the distribution of contents coverages for condominium unit owner policies in the 2008 FHCF ratemaking dataset as a function of deductible group and year built group. For the condominium unit owner TOB, 56.8% of the statewide aggregate contents coverage has a windstorm deductible of 2%, and 31.7% of the statewide aggregate contents coverage has a flat windstorm deductible between $1 and $500, which is treated as a $500 deductible in the FHCF ratemaking studies. Within the $500 deductible group, the average condominium unit owner contents coverage is $39,770 per policy. Thus, $500 deductible represents 1.26% of the average contents coverage in the $500 deductible group. Given that the majority of the condominium unit owner policies have a 2% deductible and the next three most common deductibles range from 1.26% to 5%, we will use 2% as the default deductible for the condominium unit owner relativities.

Table 2-11. Contents Coverage Distribution by Deductible Group and Year Built for Condominium Unit Owner Policies.

	Year Built					
Deductible Group	**1994 or earlier**	**1995-2001**	**2002 or later**	**Unknown**	**Total ($)**	**Total (%)**
1%	33,954,532	5,726,525	2,860,898	1,151,325	43,693,279	0.1%
2%	16,312,087,727	3,213,945,674	3,256,247,352	107,812,415	22,890,093,167	56.8%
3%	30,517,046	12,165,238	24,273,969		66,956,252	0.2%
4%	10,900,942	3,491,493	5,309,210		19,701,644	0.0%
5%	919,670,010	336,725,058	254,943,837	1,308,813	1,512,647,717	3.8%
8%				1,612,500	1,612,500	0.0%
10% to 14% (rate as 10%)	108,940,448	39,288,848	48,992,741	371,090	197,593,128	0.5%
15% or Greater (rate as 15%)	171,232,343	198,644,520	55,024,628		424,901,490	1.1%
$0	340,036,631	86,472,653	102,351,329	40,873,486	569,734,099	1.4%
$1 to $500 (rate as $500)	9,629,694,963	1,377,488,693	994,196,615	757,778,391	12,759,158,662	31.7%
$501 to $1,500 (rate as $1,000)	793,150,239	217,318,911	298,926,013	225,917,270	1,535,312,434	3.8%
$1,501 to $2,500 (rate as $2,000)	120,038,846	39,474,140	48,204,011	11,194,539	218,911,536	0.5%
Greater Than $2,500 (rate as $3,000)	25,032,172	15,484,689	13,352,874	1,537,671	55,407,406	0.1%
Totals	28,495,255,897	5,546,226,442	5,104,683,476	1,149,557,501	40,295,723,315	100.0%

Table 2-12 summarizes the distribution of contents coverages for tenant policies in the 2008 FHCF ratemaking dataset as a function of deductible group and year built group. For tenant policies, 40.8% of the statewide aggregate contents coverage is reported to have a windstorm deductible of $0, and 45.6% of the statewide aggregate contents coverage is reported to have a flat windstorm deductible between $1 and $500, which is treated as a $500 deductible in the FHCF ratemaking studies. Because a $0 deductible for a Florida windstorm policy is very unlikely, we believe that the $0 deductible group is

more likely an indicator of missing or unreported deductible amounts rather than a true indicator of the actual windstorm deductible. Within the $500 deductible group, the average tenant contents coverage is $29,175 per policy. Thus, the $500 deductible represents an average of 1.68% of the contents coverage. The next most common deductible for tenant policies is the 2% deductible. Thus, for consistency with the residential and condominium unit owner policies, we will use 2% as the default deductible for the tenant relativities.

Table 2-12. Contents Coverage Distribution by Deductible Group and Year Built for Tenant Policies.

	Year Built					
Deductible Group	**1994 or earlier**	**1995-2001**	**2002 or later**	**Unknown**	**Total ($)**	**Total (%)**
1%	5,139,722	2,147,800	1,584,400	1,157,100	10,029,022	0.1%
2%	898,873,950	244,154,056	283,620,871	38,473,199	1,465,122,076	9.6%
3%	1,403,285	46,000	217,000	42,790	1,709,075	0.0%
4%	417,000				417,000	0.0%
5%	26,383,169	7,023,700	18,370,591	16,138,018	67,915,478	0.4%
10% to 14% (rate as 10%)	3,201,364	1,320,780	1,445,815	13,531,158	19,499,117	0.1%
15% or Greater (rate as 15%)	7,063,000	10,220,200	3,031,000		20,314,200	0.1%
$0	1,840,376,437	447,223,822	279,841,562	3,659,708,823	6,227,150,644	40.8%
$1 to $500 (rate as $500)	3,201,987,222	1,245,065,235	998,295,571	1,508,170,602	6,953,518,630	45.6%
$501 to $1,500 (rate as $1,000)	120,612,390	56,822,794	69,751,038	216,998,387	464,184,609	3.0%
$1,501 to $2,500 (rate as $2,000)	2,416,127	946,000	1,496,000	7,226,356	12,084,483	0.1%
Greater Than $2,500 (rate as $3,000)	2,229,104	495,975	769,037	8,647,723	12,141,839	0.1%
Totals	6,110,102,770	2,015,466,362	1,658,422,885	5,470,094,156	15,254,086,173	100.0%

2.7.2 Coverage Ratios

The second insurance parameter of potential importance to the relativity results is the ratio of secondary to primary coverages. For a typical residential windstorm policy, there are four main coverages: (A) Building, (B) Appurtenant Structures, (C) Contents, and (D) Additional Living Expenses (ALE). Typically, the building coverage (Coverage A) is taken to be the primary coverage for owner occupied, residential (1-4 unit) policies, whereas the contents coverage (Coverage C) is taken to be the primary coverage for condominium unit owner or tenant policies.

In general, the rates at which Coverage A, B, C, and D losses are reduced by improved construction methods depend on the type of mitigation and the location of the structure. Therefore, it is important that the default coverage ratios used in the analysis be representative of typical Florida residential windstorm exposures.

Table 2-13 summarizes the average coverage ratios compiled from the 2008 FHCF ratemaking dataset for single-family and multi-family buildings. We see that the average coverage ratios are 8.5%, 49.9% and 17.4% for Coverages B, C, and D, respectively, for SF homes. For multi-family buildings, we have summed the commercial-residential, condominium unit owner, and tenant's exposure. The resulting multi-family coverage ratios are 17% and 5.6%, for Coverages B, C, and D, respectively. Coverage B includes attached and detached structures, such as aluminum frame screen enclosures, fences, storage sheds, gazebos, etc. These structures are not built to the same building code requirements as dwellings. The data in Twisdale et al. (2007) suggests that these types of structures are more readily damaged than the dwelling and add to the loss costs at a faster rate than the dwelling. They are also not easily mitigated for wind effects nor are there current, proven standards for mitigating these types of structures for wind hazards. Hence, and as will be discussed later in this report, the wind mitigation rate differentials developed in this study do not apply to these types of structures. We therefore exclude Coverage B in this study. Another key assumption is that any attached structures that are covered under Coverage A are excluded from that portion of the wind premium to which the resulting rate differential is applied.

The set of coverages that we use in this study are given in Table 2-14. We have rounded up the contents and ALE percentages for single-family. For multi-family, we have rounded contents up and ALE down since it appears that tenant's exposure is under-represented in the FHCF exposure data. Contents

and ALE coverages are included for both single-family and multi-family since they derive from damage to the dwelling structure. A mitigated structure will have fewer failures of the building envelope and hence fewer contents losses and reduced loss of use.

Table 2-13. Average Coverage Ratios for Single-Family (1-4 Units) and Multi-Family (5+ Units) Occupancies.

Type of Business	*Building*	*Apprt. Str.*	*Contents*	*ALE*
Single-Family (1-4 units)	100%	8.5%	49.9%	17.4%
Multi-Family (5+ units)	100%	21.7%	25.2%	5.6%

Table 2-14. Default Coverage Ratios Used in this Study for Single-Family (1-4 Units) and Multi-Family (5+ Units) Occupancies.

Type of Business	*Building*	*Apprt. Str.*	*Contents*	*ALE*
Single-Family (1-4 units)	100%	0.0%	50.0%	20.0%
Multi-Family (5+ units)	100%	0.0%	30.0%	5.0%

3 New Insurance, Damage, and Engineering Data

3.1 General

Since the 2002 loss relativity studies were completed, there is a significant amount of new data relevant to loss mitigation for residential buildings. These data include insurance loss data from Florida hurricanes, hurricane damage surveys, and engineering data from wind tunnel and laboratory tests. We have considered much of this new information for purposes of updating and validating the loss relativities. This section highlights these new data and resulting analyses.

A major focus of this study included the analysis of insurance data from the 2004-2005 Florida hurricanes. These hurricanes include Charley, Frances, Ivan, Jeanne, Dennis, Katrina, and Wilma.[10] We were able to work directly with several insurance companies to obtain data that we could analyze in an anonymous statistical approach for purposes of understanding building performance in hurricanes. The types of data obtained included both policy level and claim level information. These types of data are useful for determining the effectiveness of mitigation features, the impact of non-modeled characteristics on insured losses, and how physical damage to a structure translates into economic losses. Sections 3.2 through 3.4 summarize the new insurance data analysis research that was conducted during this project. This work is obviously very open-ended in nature and much more work is needed to continue to improve our understanding and modeling of the many interrelated variables that affect physical damage and loss mitigation.

In addition to new insurance data, the hurricanes of 2004-5 provided opportunities for engineering surveys of physical damage to residential buildings. Survey data have been collected by various organizations for different purposes. For purposes of quantification of loss mitigation effectiveness, we include a few summaries of data collected by the University of Florida and ARA. The data from these organizations was collected in a scientific fashion that included both damaged and undamaged structures.[11] Section 3.5 summarizes these physical damage observations, with emphasis on Hurricane Charley.

The new engineering data consists of wind tunnel tests on model single-family houses with different roof shapes and slopes. These tests also included different terrains, including treed terrains, and building spacings. Impact tests have been conducted on unprotected glazing and shutter products. In addition, full scale pressure measurements on real buildings are available from the Florida Coastal Monitoring Program. This new information has allowed for model improvements, which are discussed in Section 3.6.1. Section 3.6.2 also includes a summary of the new work on loss modeling, which has been incorporated into this study from the insurance claim folder data.

3.2 Insurance Data Summary

Insurance company data provide key inputs for: (1) understanding the relationships between physical damage and insured loss and (2) validating the effectiveness of wind mitigation features in reducing hurricane losses. Insurance data requirements for this project include both policy level and claim folder level data. For purposes of this study, a primary distinction between policy level data and claim folder level data is that policy level data summarize the total loss by coverage, whereas claim folder level

[10] Hurricane Charley is the only recent hurricane to hit Florida with peak gust windspeeds greater than 120 mph. High windspeeds are needed to validate the effectiveness of wind mitigation features, since at low windspeeds the losses are often dominated by roof cover failures, attached and detached structural failures, and damage to components other than the structural envelope.

[11] We have not attempted to address the many sources of "anecdotal" type field data in this project. Anecdotal data collection approaches focus on damage observations without attempting to determine the frequency of damage (by considering both damage and undamaged structures in a particular wind speed swath sample area). Anecdotal data are primarily useful for observing failure mode patterns.

data include photos and show an itemized breakdown of the physical damage and the associated repair costs. Policy level data include all the insurer's policies in the state and the amount of loss for selected hurricanes. Zero losses must be included in the policy level data analysis since the analysis of the fractions of loss must be built up with the correct denominator or exposure to the storm. Policy level data provide high level information on loss trends, considering data elements like year built, number of stories, shutters, roof shape, etc.

In contrast to policy level data, claim folder level data include information for only the policies that have claims. That is, claim folder level data is biased in the sense that it is conditioned on the insured contacting his insurance company and reporting a claim. If the building was not damaged or if the loss was below the deductible, a claim record generally does not exist. Hence, claim folder level data are primarily useful for understanding how physical damage translates into economic loss. Given damage to the building, claim folder level data can be used to understand and validate how a model "adjusts" the damage property into an insured loss. Hence, individual claim folder data promote understanding of the relationship of physical damage and the costs of repair, reconstruction, contents damage, and loss of use. Both policy level data and claim folder level data are needed to help validate the wind mitigation effectiveness of building code improvements in Florida.

Significant amounts of data are now available that were not available in the 2002 studies. Recent Florida hurricanes include: Charley, Frances, Ivan, Jeanne, Dennis, Katrina, and Wilma. Policy and claim level loss data from these storms will be useful in understanding and validating the effectiveness of mitigation features, the impact of non-modeled characteristics on losses, and how physical damage to a structure translates into economic losses. It is important to realize that Hurricane Charley is the only Florida hurricane since 2002 with peak gust windspeeds much greater than 120 mph.

Table 3-1 summarizes the data types and number of hurricanes that we used for this project. With the help of the Office of Insurance Regulation, we worked with eight different insurance companies, identified as Company A through H in the table. Each company provided data in their own format, protected by a nondisclosure agreement. We have analyzed this data in an anonymous statistical manner for purposes of this research. The insurance companies have had no say in how we analyzed the data or what results were obtained. We received policy level data from 7 different companies and claim folder level data from 4 companies. All of the data analyzed were for Florida hurricanes and Florida residences.

Table 3-1. Insurance Data for Validation of Loss Mitigation Relativities.

Insurance Company	*Policy Level Data*	*Sample of Claim Level Data*	*No. of Hurricanes*
A	Yes	Yes	5
B	Yes	No	7
C	Yes	No	7
D	Yes	No	1
E	Yes	Yes	7
F	Yes	Yes	7
G	Yes	No	3
H	No	Yes	4
Total	--	--	41

The analysis focuses on single family homes. The datasets did not have sufficient construction information for multifamily buildings to allow analysis of the effects of mitigation features for those types of residences.

3.3 Insurance Policy Level Losses

We analyzed policy level data for all companies and hurricanes but no results are presented for Company G due to the small number of available policies. The data fields provided by each company were different. For some companies, the roof shape and number of stories variables were available for all policies while for others these variables were only available for houses that had been inspected for eligibility for the 2002 mitigation credits. For some companies only total claim paid (sum of A, B, C, D loss) was provided while for others the loss amounts by coverage were available. Another significant difference is that each insurance company's dataset was for a different number of hurricanes (e.g., Company D had only one hurricane while Company F had 7).

The policy level data consist of building-by-building data with the insurer's exposure prior to the storm as the exposure data set and the insurer's losses by coverage as the loss data set. For each building in these data sets, we use the construction features that the insurer has on the building (such as number of stories, construction type, and year built, value, roof cover type, and available details on wind mitigation features) and analyze this data in various ways. Methods of analysis include:

1. Loss vs. Windspeed
2. Loss vs. Other Variables
3. Average Loss
4. Loss vs. Modeled Loss
5. Multivariate Statistical Analysis

Loss refers to the insured loss for that event and can include one or more coverages. The loss ($) is often normalized by coverage limit ($) to produce a non-dimensional variable ("loss fraction").

Loss vs. Windspeed. One of the most powerful ways to analyze and understand the effects of wind mitigation features is to analyze losses by windspeed bin. That is, the location of each building in the portfolio is used along with modeled estimates of the peak windspeeds at each building location for that hurricane. Windspeed is treated as the independent variable since the type and nature of loss is heavily dependent on windspeed. Losses at low windspeeds may have absolutely nothing to do with whether or not the building has wind mitigation features. Many mitigation features only become noticeable at windspeeds that begin to stress the building envelope. It is important to determine if there are significant differences in losses at higher windspeeds. This analysis technique has been used in model development and validation for some time, but it is limited by the amount of information insurance companies have on the insured structures. We emphasize that if you don't know the mitigation construction features of the building at a policy level, obviously, one cannot use insurance policy level loss data to infer much about the details of how well certain wind mitigation features have performed.

Appendix B contains information on Florida hurricanes that will be used in the policy level loss vs. windspeed analysis. Each hurricane windfield is modeled and reconstructed using track location data, central pressure measurements, dropsondes, and, most importantly, anemometer data. The best possible windspeed swath is produced for that storm. The windspeed swath data is then mapped to each policy in the dataset. The windspeed variable can be the reference open terrain windspeed or the terrain dependent windspeed at the policy location.

Figure 3-1 illustrates several datasets of single-family building loss vs. windspeed for four Florida hurricanes. The top 4 plots in the figure are normalized dwelling loss (Coverage A) and the bottom 4 plots are "other structures" (Coverage B). The reference windspeed is the peak gust in open terrain. Hence, terrain-adjusted windspeeds are not used in these plots. Each point represents one policy. The scatter plots illustrate the large variance of a typical dataset resulting from different terrains, buildings, and wind mitigation features. The results for Coverage B indicate that the coverage limit (generally 10% of Coverage A) can easily be reached for windspeeds less than 100 mph.

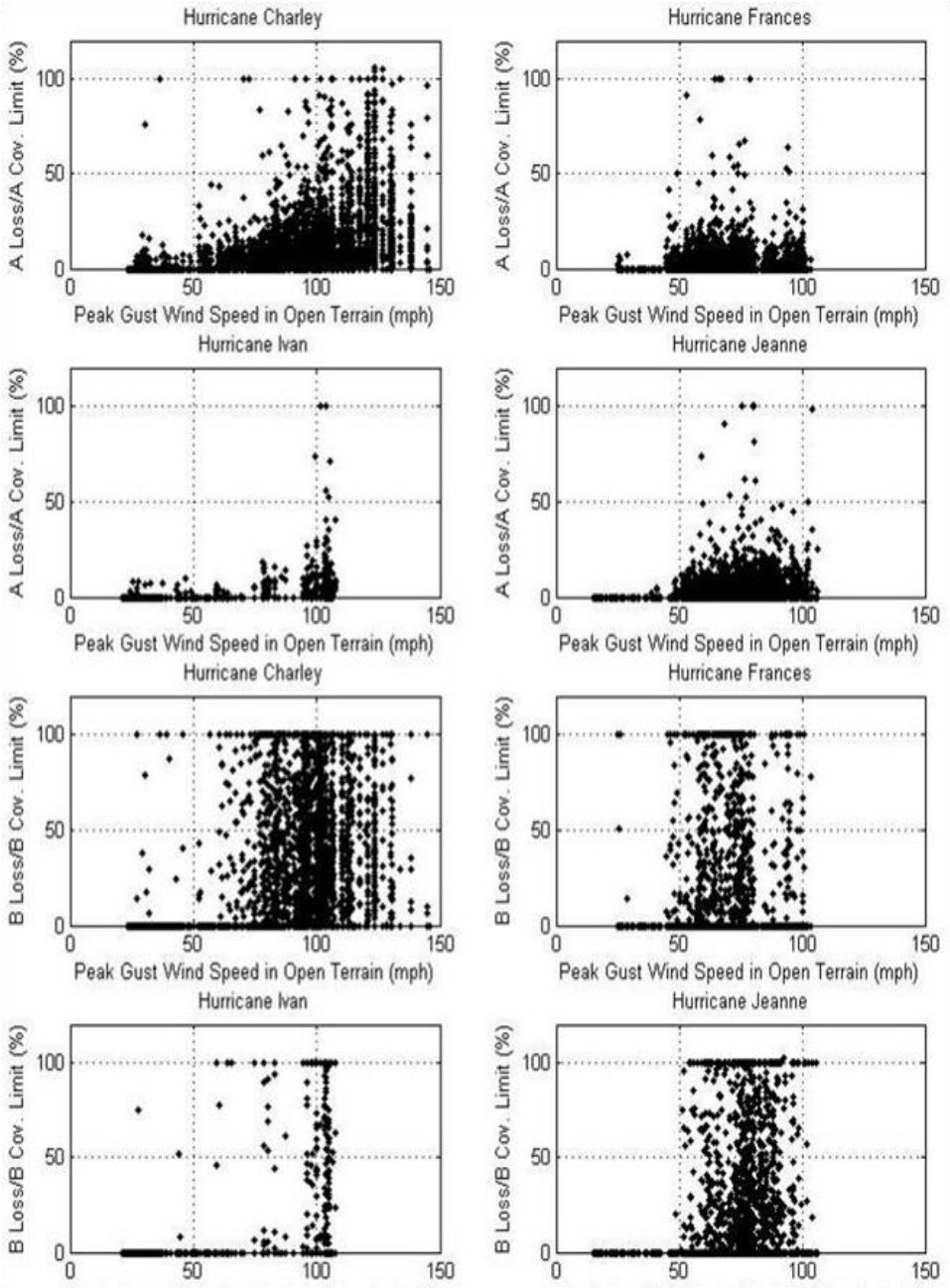


Figure 3-1. Sample Single-Family Policy Level Losses vs. Windspeed.

The effect of averaging the loss by windspeed bin and using a simple 3 point smoothing technique produces the mean loss functions in Figure 3-2. In each plot, the scale of the y axis has been reduced as needed to clearly show the shape of the mean loss functions. In some cases, the mean losses are a few percent or less for hurricanes in which the peak windspeeds are less than 100 mph. The dramatic, nonlinear shape of these mean loss functions is clearly apparent, demonstrating the well known shape of model-developed wind loss functions.[12] These empirical curves are jagged near the top because

[12] Recall that the pressure load on a structure is proportional to the square of the windspeed. The wind-borne debris environment is generally proportional to the cube or higher exponent of windspeed. Hence, loss functions are highly nonlinear in windspeed.

of the lack of enough policies that experienced high windspeeds in these datasets. Comparing Figure 3-1 and Figure 3-2 clearly shows the power of analyzing loss data by using windspeed as the independent variable. This approach solves a lot of problems in defining the spatial boundaries of the data set.

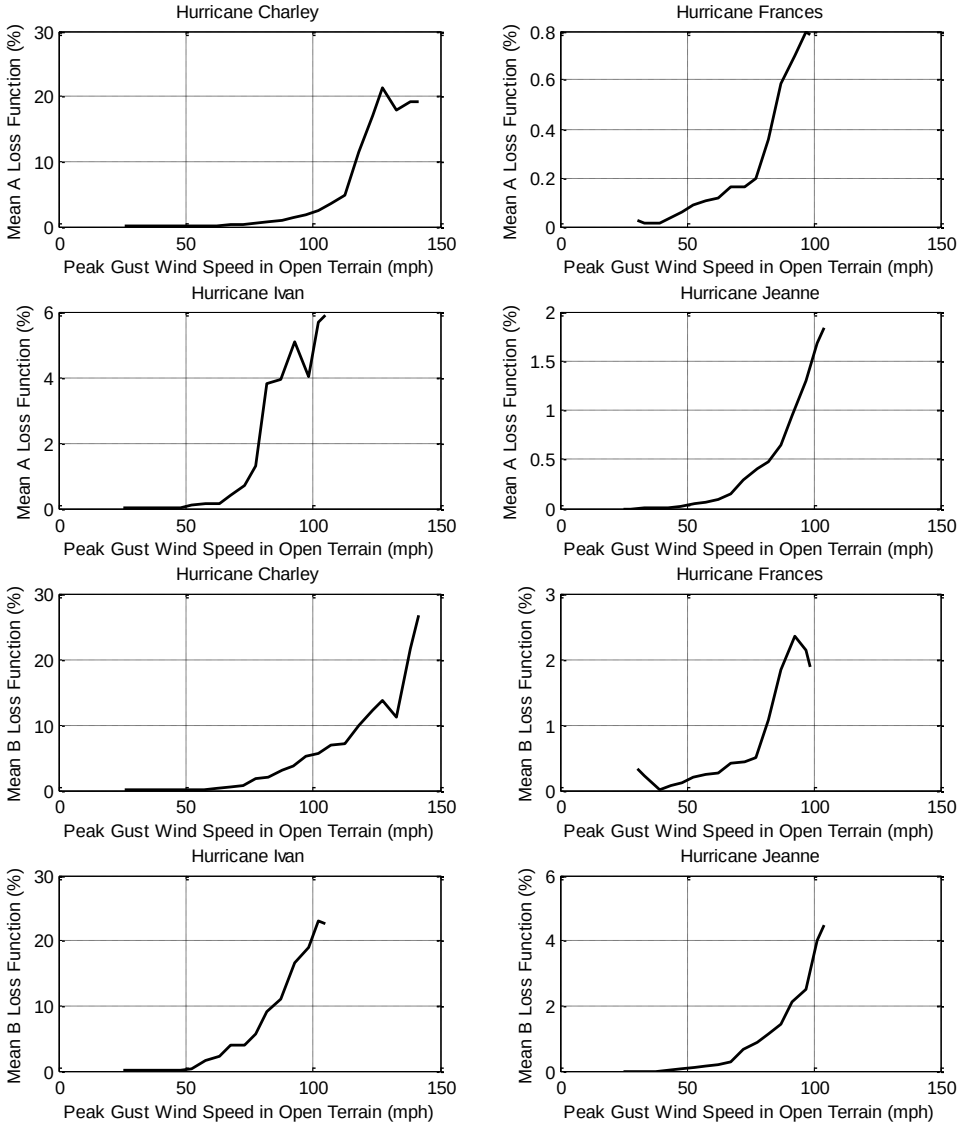


Figure 3-2. Example Single-Family Policy Level Mean Losses (3-point Smoothing) vs. Windspeed.

Loss vs. Other Variables. This technique includes analysis of loss against any selected variable in the policy data set, such as location or year built. Since windspeed is not an independent variable, care is needed in the interpretation of these results. Within an area of near constant windspeed, this approach can generally be used successfully.

Average Loss and Average Annual Loss. Average loss can be computed in several ways. The empirical approach involves computing the average loss for policies conditional on one or more variables. The average losses can then be compared to quantify average effects.

Another approach is to compute the average (expected value) annual loss by integrating an empirically derived windspeed loss function with the windspeed probability density function for that location, according to

$$E(L) = \sum_{n=0}^{+\infty} \left[\int_{0}^{+\infty} D(v)\, p_v(v) dv \cdot n \cdot p_n(n) \right] \qquad \textit{(3-1)}$$

where: v is the windspeed; $D(v)$ is the loss function (the average loss given windspeed); $p_v(v)$ is the probability density function (PDF) of windspeed affecting the location given a hurricane occurrence; n is the variable number of hurricane occurrences in a year that affect the area; and $p_n(n)$ is the PDF for n. The variable L is the expected loss variable. The difference in average annual expected losses, *E(L)*, for the presence/absence of a wind mitigation construction features, provides a fundamental way to estimate the expected effects of wind loss mitigation.

Loss vs. Modeled Loss. This analysis is useful for model validation. Modeled loss is computed from a model with the portfolio and building characteristics input to the model. The more building characteristics data that are available on a policy-level basis, the more meaningful are the results. Modeled loss also depends on the accuracy of the windfield model for that hurricane. A 10 mph error in windspeed can make a huge difference in modeled loss (due to the characteristic nonlinear shape of loss functions).

Multivariate Statistical Analysis. This approach involves analyzing the loss data with advanced statistical methods such as general linear models, cluster analysis, and analysis of variance, etc. Without large amounts of data, good quality datasets with key building characteristics, and the introduction of windspeed and terrain, the resulting analysis will be heavily dependent on the particular data set analyzed and may not be repeatable over multiple data sets. The large number of factors, the effect of terrain, and the actual windspeed experienced at the building all combine to make the analysis complex and interpretation difficult. Performing multivariate analysis without introducing windspeed or terrain for each building will result in significant levels of unexplained variance in the results.

In summary, our analysis methodology focuses on extracting all possible construction features from each dataset and analyzing differences in loss based on wind mitigation feature. We develop empirical loss functions by analyzing loss as a function of windspeed. Company-specific empirical loss functions for various mitigation features are presented in the following sections. It is important to note that for the cases where only total claim paid (i.e., sum of A, B, C, and D loss) was provided, we added the hurricane deductible to convert the total insured loss to total ground-up loss.

3.3.1 Pre-FBC vs. Post-FBC

All houses permitted in Florida beginning in March 2002 have been built to the Florida Building Code. The 2001 FBC included a number of improvements in the strength requirements for new buildings. A simple analysis of insurance company data sets can be used to compare losses based on year built. Figure 3-3 through Figure 3-5 illustrates averaged and smoothed loss functions for houses built prior to 2002 (pre-FBC) and during or after 2002 (post-FBC).

The data in Figure 3-3 are for 1 story houses averaged over 4 hurricanes and separated into two groups according to year built. These empirical loss functions are significantly different and show dramatic reductions in loss for post-FBC construction. For example, we see that at about 125 mph winds that the mean loss for pre-FBC is about 25%, while for post-FBC it is about 5% of the Coverage A limit.

That significant difference corresponds to about an 80% loss reduction in that windspeed range. [13]

Figure 3-4 shows the same data for two-story homes. We see that the losses are greater for two story homes than one story homes and that the effect of the pre- vs. post-FBC continues to be significant in reducing losses (70 to 80% loss reduction at the higher windspeeds).

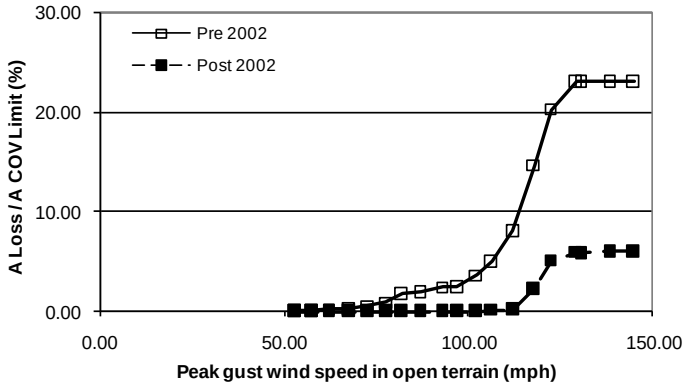


Figure 3-3. Smoothed Empirical Building Loss Functions for a Pre-FBC and a Post-FBC One-Story House (Company A).

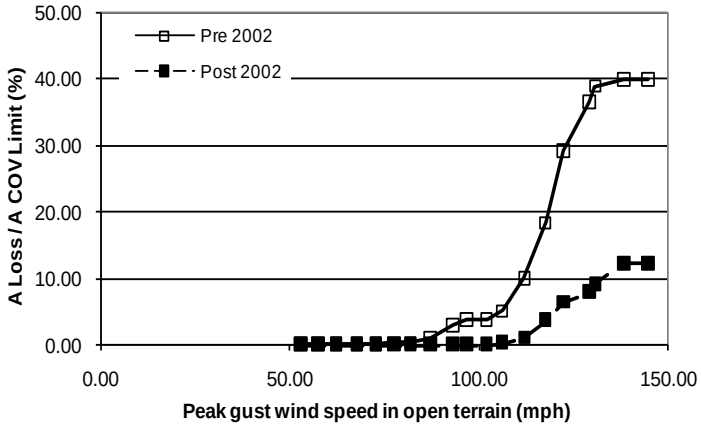


Figure 3-4. Smoothed Empirical Building Loss Functions for a Pre-FBC 2002 and a Post-FBC 2002 Two-Story House (Company A).

Other Companies. Figure 3-5 shows the FBC year-built data for different companies averaged over hurricanes and number of stories. The vertical axis in Figure 3-5 is the ground up loss normalized by the sum of A, B, C, D coverage limit. That is, these companies did not provide loss by individual coverage, so we only had the total claim amounts to work with. The empirical loss functions shown in Figure 3-5 differ for each company. The number of hurricanes available varies by insurance company and there are inherent differences between the coverage distributions of different companies. The main purpose of presenting results for different companies is to demonstrate that the loss reduction trend for post- FBC construction is visible for all the companies, even when the loss data includes losses (for example Coverage B losses) not related to the FBC. The effect of including Coverage B losses is to weaken the effect of the pre- and post-FBC comparisons.

Pre- and Post-FBC Summary. The empirical plots in Figure 3-3 to Figure 3-5 obviously are not correct since the mean loss function becomes horizontal at less than 100% loss. However, even with the limitation that these storms did not have extremely high windspeeds, the differences in the loss functions are highly significant. Post-FBC homes, on average, perform significantly better than pre-FBC homes. For windspeeds less than about 80 mph, there is little difference in loss, whereas at windspeeds greater than about 120 mph, there are enormous differences in loss. Low windspeed losses are not always well-correlated with year built since a large amount of the losses result from components outside the building envelope, such as exterior structures, light fixtures, air conditioning equipment, etc.

[13] We have capped the loss functions at the point where the windspeed data ends (generally 110 to 140 mph, depending on the storms used) or where there were too few loss data points to average in that windspeed bin. This capping approach results in the empirical loss functions turning horizontal in these plots.

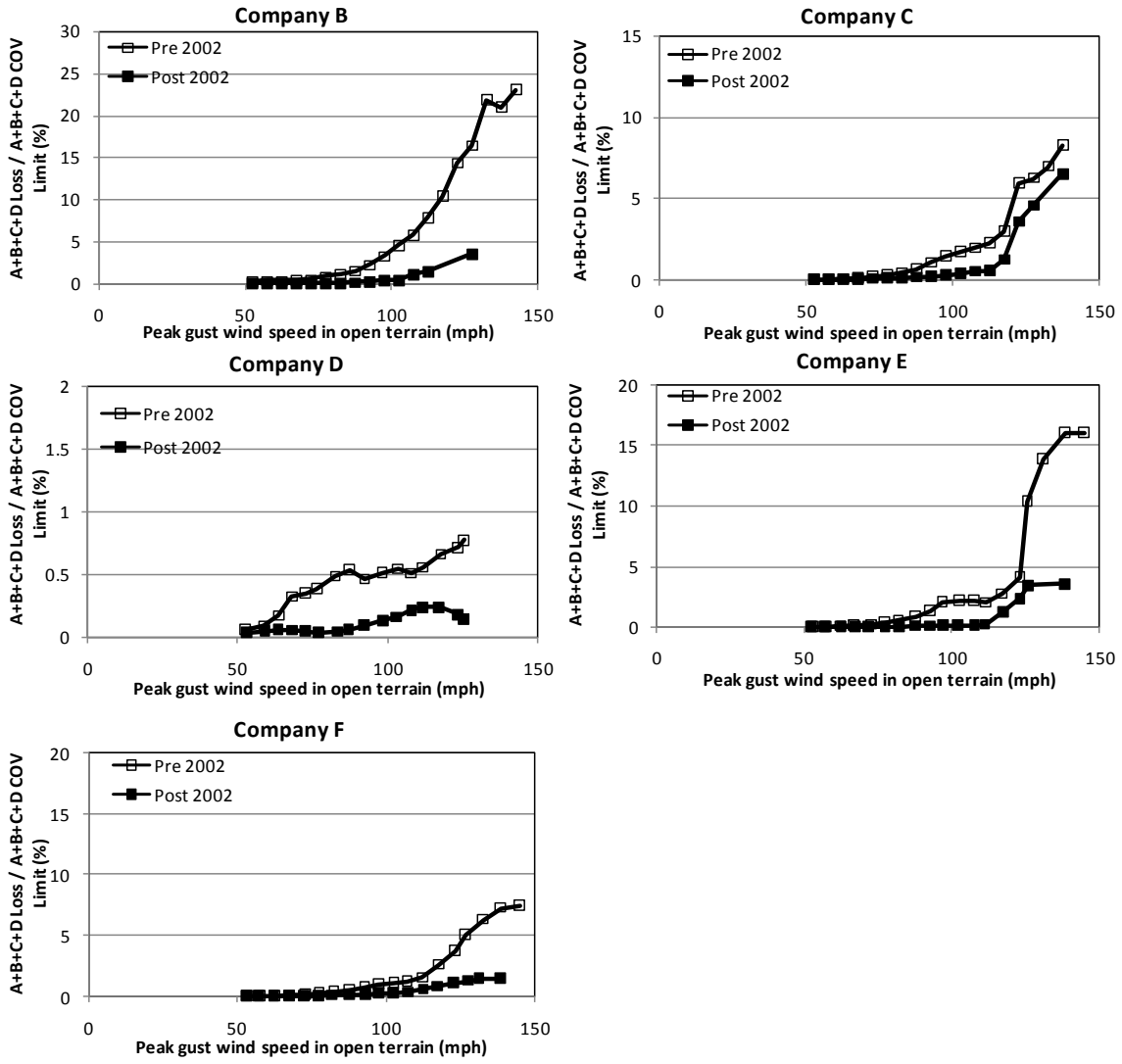


Figure 3-5. Empirical Building Loss Functions (Smoothed) for Pre-FBC and Post-FBC Houses for Different Insurance Companies.

The loss functions in these figures can be numerically integrated over the wind hazard function to produce an expected value calculation of average annual loss reduction according to Equation 3-1. We did this by performing Monte Carlo simulations using the hurricane risk for different Florida locations and the capped empirical loss functions for Company A. The computed expected value of loss reduction is 85% for post-FBC construction when compared to pre-FBC construction. We note that these insurance data trends tend to support the relativities produced in 2002 for new construction, which show relatively large loss reductions for post-FBC construction. For example, the 2002 predicted loss relativities for Terrain B FBC single-family construction with opening protection were in the range of 0.23 to 0.48 (Table 4-1, Other Roof Deck), whereas the loss relativities for pre-FBC roof cover homes with no shutters or SWR were in the range of 0.75 to 2.37 [Table 3-2 (ARA, 2002a)]. If we take the midpoint of both of these ranges, we have loss relativities of 0.36 and 1.56 for the two groups. The percent loss reduction would be (1.56-0.36)/1.56 = 77%. The insurance data results indicate that these differences in loss relativities appear to be generally reasonable.

3.3.2 Year Built

Trend Analysis. Figure 3-6 is a scatter plot of Coverage A % loss *vs.* year built for Company A houses with a loss. That is, the plot is conditional on the home having a claim. In these types of plots, the loss % cannot be interpreted in an absolute sense and one should only use this type of data for trend analysis. We see that the plot includes a few losses at 100% or greater. The trend line in the figure shows the mean loss %, given that the house had a loss claim. The mean trend line shows a visible reduction in loss for recently constructed homes.

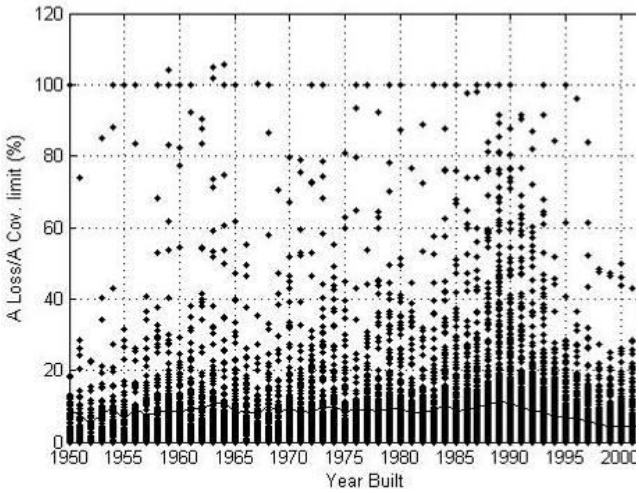


Figure 3-6. Coverage A Loss % vs. Year Built for Houses with Insurance Claims (Company A).

Mean Loss Fraction. A second approach to analyzing year built data is to include all the data with zero losses, as is done in Section 3.3.1. This approach allows us to quantify Coverage A loss fraction by year built. Figure 3-7 plots Company A mean Coverage A loss fraction *vs.* year built, including all properties with no claims. That is, the plot includes the mean loss of all homes in the dataset, including those with zero loss. The figures show results for 4 windspeed intervals: all windspeeds, greater than 120 mph, 100-120 mph, and 80-100 mph windspeeds. The all windspeed plot shows a noticeable increase in mean loss for homes built in the late 1980s and early 1990s. We use 30 mph winds in the all windspeed category. Hence, locations with winds <30 mph are not included in the all windspeed plots.

Beginning in 1995, the losses show a reduction that continues down with year built. We note that high wind standards began to be adapted in 1993 and the FBC became effective on March 1, 2002. We believe the most significant wind mitigation plot is the bottom plot for winds >120 mph windspeed, since a larger portion of these losses are likely attributable to the dwelling construction (instead of condition of roof cover). The reduction for post-FBC houses is also visible in the >120 mph plot.

We emphasize that roof cover losses are generally a large component of hurricane losses. Recently installed roof covers generally do better that aged roof covers and these effects are buried in these types of plots. The losses in the 80-100 mph plot are likely dominated by roof cover losses from aging roof covers, window and door leaks, and attached and detached structure losses, as opposed to building structural envelope failures. The 80-100 mph plot shows an almost perfect progression of loss with year built back about 15 years to 1990. Detailed analysis of claim folders is required to reveal these loss contributions, the affects of year built, the role of aging roof covers, tree fall, and the effects of other factors.

Figure 3-6 and Figure 3-7 show similar trends, but the normalization of the data clearly affects the magnitude of the loss. Again, normalization of the data in Figure 3-6 by all the zero claims produces the mean losses in Figure 3-7. Clearly, this normalization depends on the number of zero claims in the dataset and the number of houses in the dataset that weren't affected by the hurricane.

Figure 3-8 to Figure 3-11 show mean ground up loss for combined coverages by year built for Companies B, C, E, and F. The data provided from Companies B, C, and E did not have individual coverage losses. However, we still see the trends of reduced loss for more recently built homes.

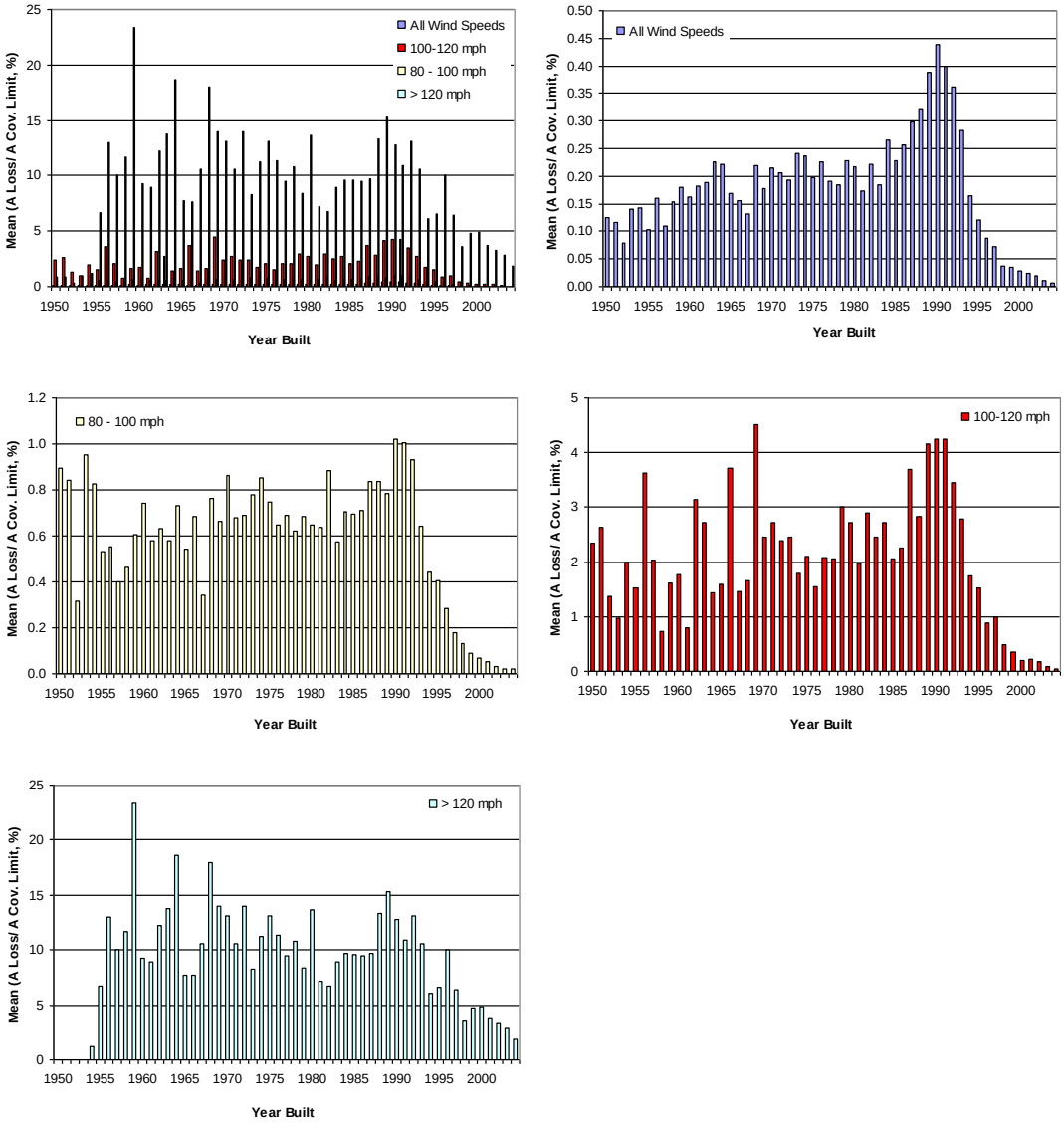


Figure 3-7. Coverage A Loss % vs. Year Built, including Houses with No Claims (Company A).

Figure 3-12 shows mean % A, B, C and D loss vs. year built, including all properties with no claims for Company D. The gradual decrease in mean loss for houses built after 1995 is clearly evident. We see the expected result that Coverage B losses, as a fraction of Coverage B limit, exceeds the loss fractions for Coverage A.

3.3.3 Number of Stories

The effect of the number of stories for a single-family dwelling is illustrated in Figure 3-13 and Figure 3-14. We see a notable difference in the smoothed empirical loss functions for one vs. two stories. Two-story homes are more easily damaged than one-story homes by virtue of the increased height of the building. Increased height results in higher windspeeds (which increase non-linearly with height above ground) and increased number of impacts by wind borne debris. At high windspeeds, the relative effect of one vs. two stories is similar for both pre- and post-FBC homes, even though the absolute loss levels for pre- and post-FBC are quite different.

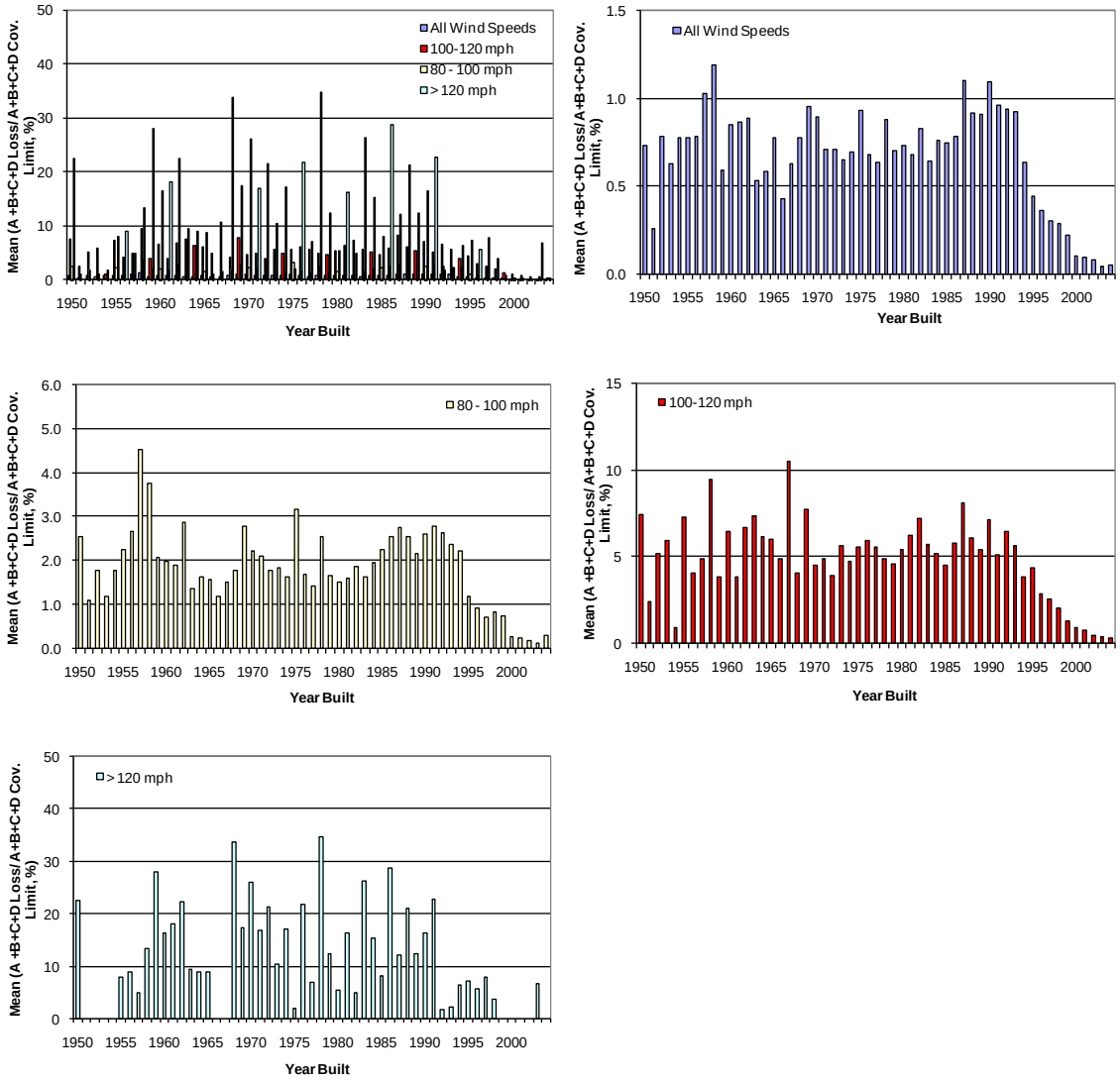


Figure 3-8. Coverage A+B+C+D Loss % vs. Year Built, including Houses with No Claims (Company B).

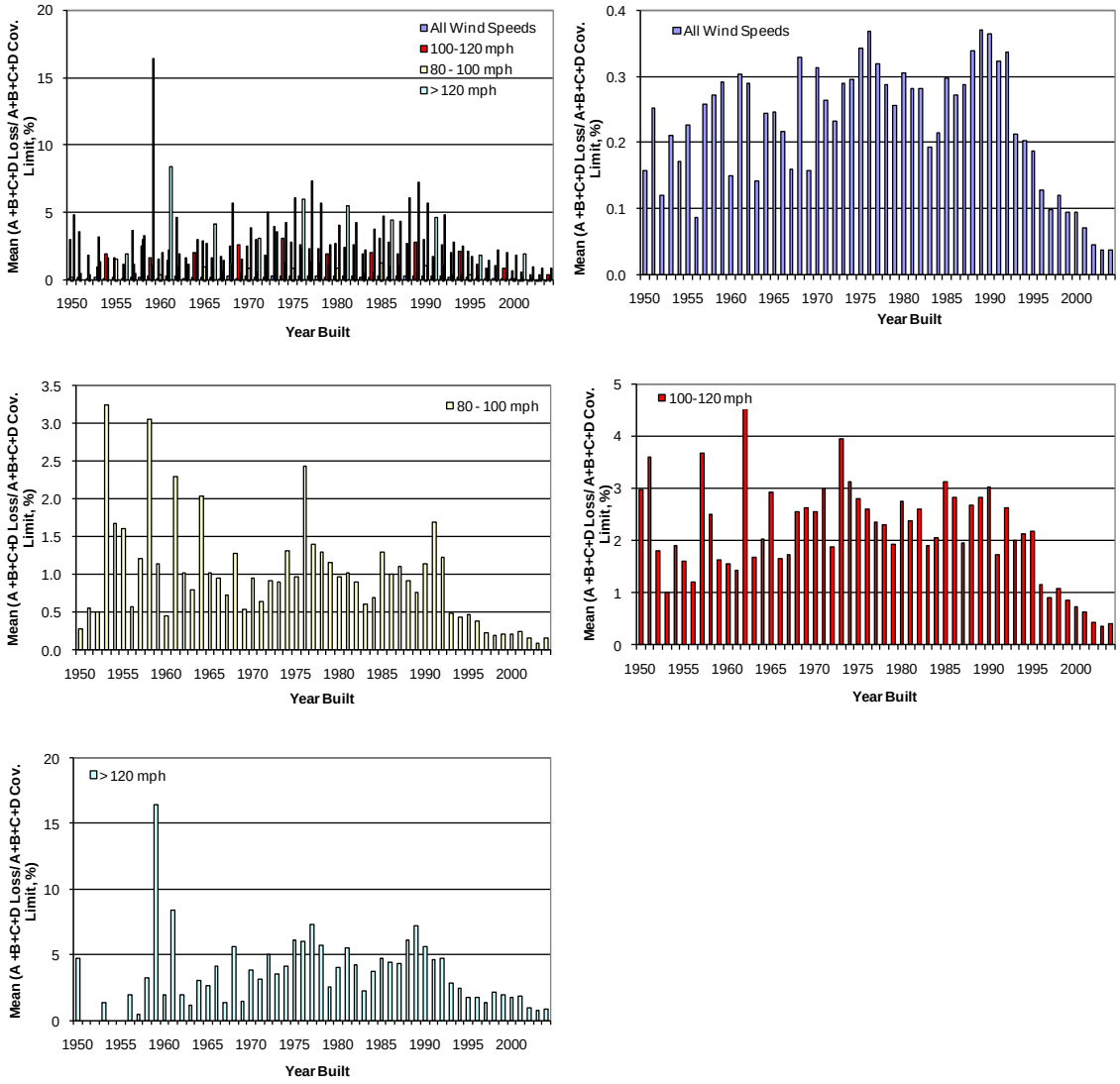


Figure 3-9. Coverage A+B+C+D Loss % vs. Year Built, including Houses with No Claims (Company C).

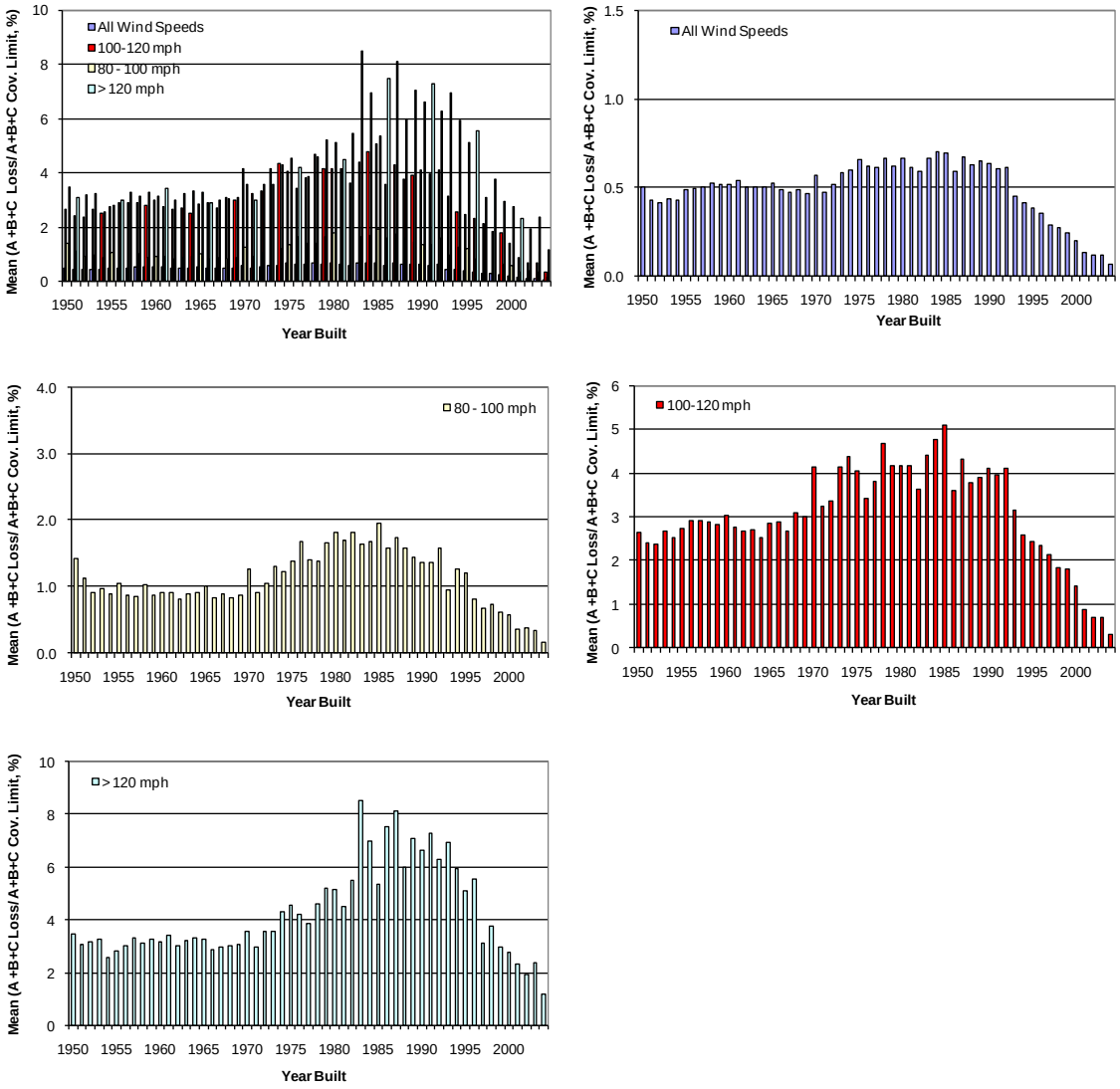


Figure 3-10. Coverage A+B+C Loss % vs. Year Built, including Houses with No Claims (Company E).

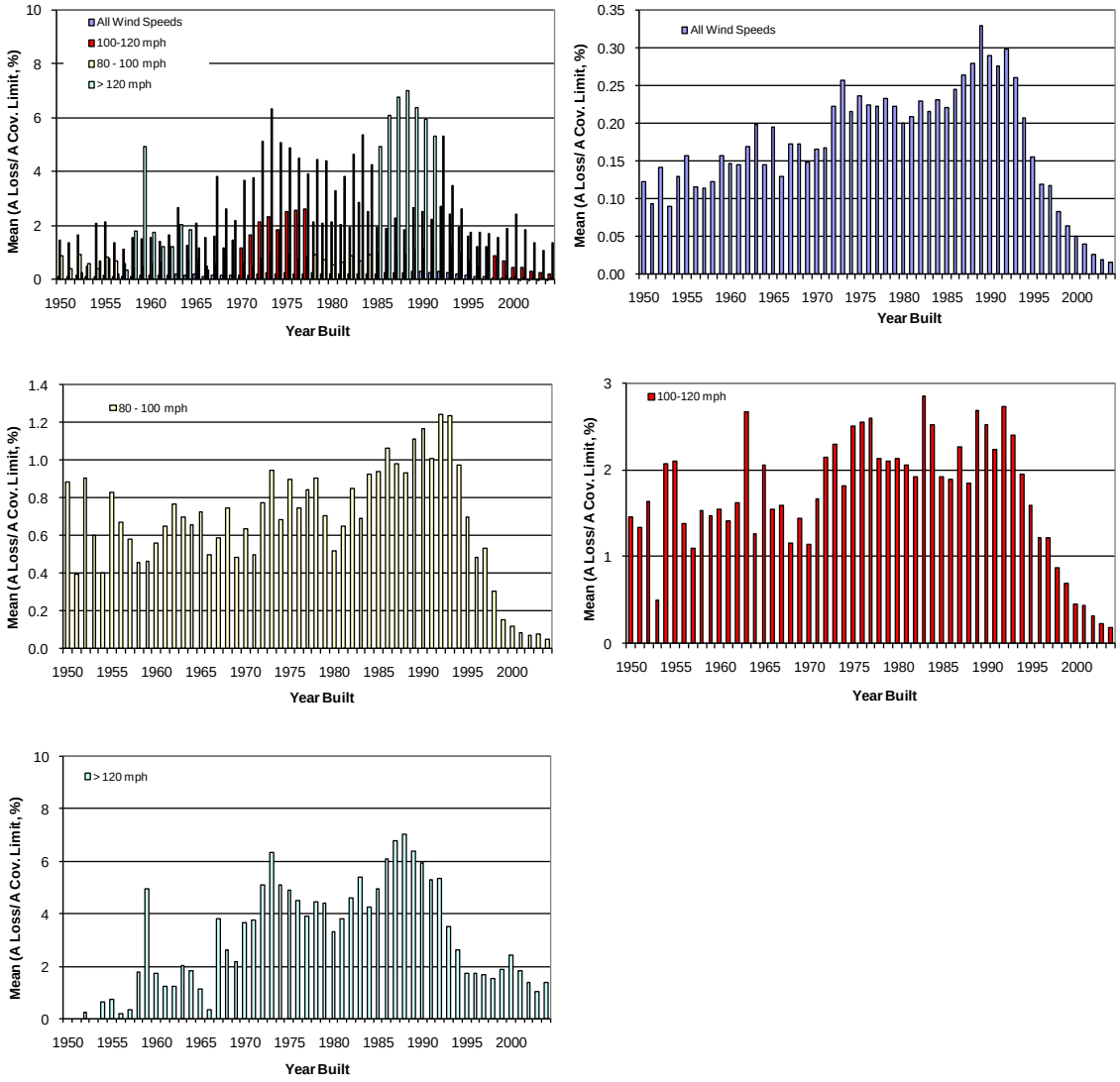


Figure 3-11. Coverage A Loss % vs. Year Built, including Houses with No Claims (Company F).

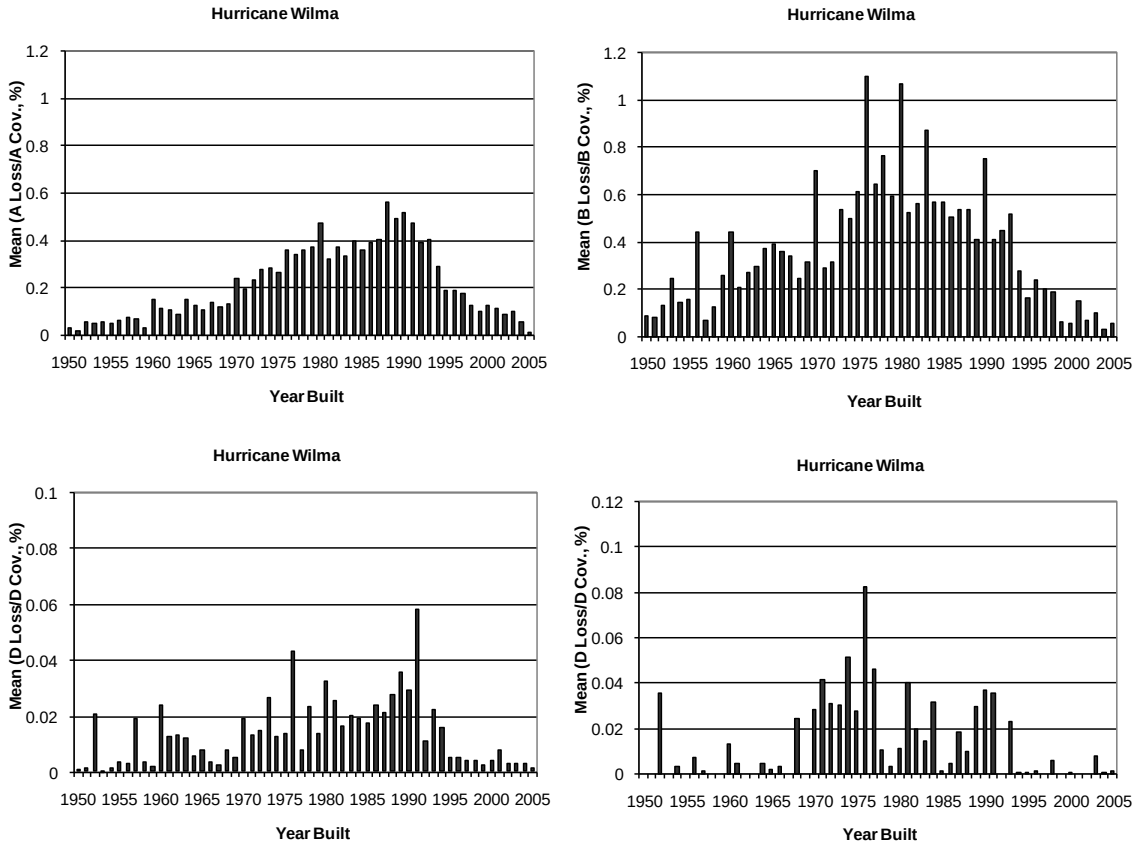


Figure 3-12. Coverage A, B, C, and D Losses % vs. Year Built for all Windspeeds in Hurricane Wilma, Including Houses with No Claims (Company D).

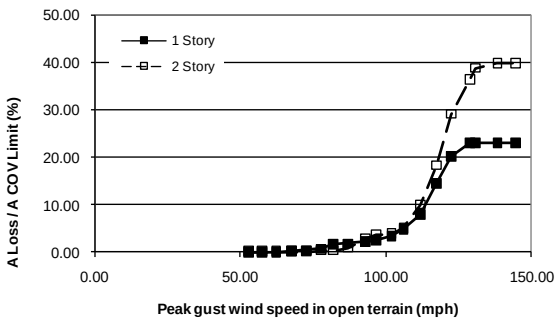


Figure 3-13. Smoothed Empirical Building Loss Functions for a One-Story and a Two-Story Pre-FBC House (Company A).

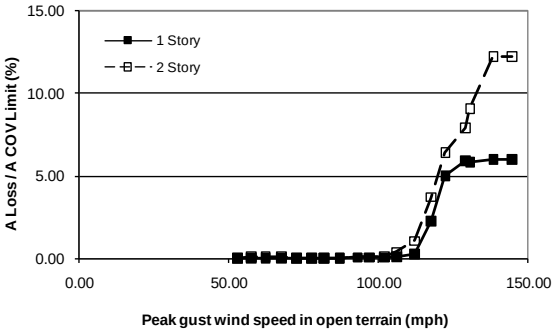


Figure 3-14. Smoothed Empirical Building Loss Functions for a One-Story and a Two-story Post-FBC House (Company A).

Using Equation 3-1, we computed the differences in average annual loss for one- and two-story homes to be about 20% for pre-FBC and 80% for post-FBC construction for a Tampa location. These data clearly indicate that one-story homes have notably fewer losses than two-story homes.

Number of stories was not included in the 2002 Loss Relativity Study for single-family homes. There was concern that there wasn't enough data to support the large differences in relativities between

one- and two-story homes that the HURLOSS model was producing. However, number of stories was included in several insurance company filings shortly thereafter and has also been included in the Florida Home Structure Rating System (HSRS). The loss reduction for one-story homes in these previous studies was approximately 10 to 50%, with the greater differences for weaker buildings.

3.3.4 Roof Shape

The smoothed empirical loss functions for gable vs. hip roof shape (Company A) are illustrated in Figure 3-15 for the pre-FBC homes. Figure 3-16 shows the same data for Company F derived using that company's data for inspected houses only. Gables are not an efficient aerodynamic shape and the flow separation produces higher negative pressures than those experienced by hip roof shapes. Gable roof shapes will generally have higher roof cover losses than hips and, in extreme winds, will experience higher roof deck losses and whole roof failures than hips. Figure 3-15 and Figure 3-16 shows that there is relatively small or no difference between the two curves for windspeeds < 90 mph but as windspeed increases hip roof shape tends to behave much better than gable roof shape. The 2002 loss relativities had 20-30% difference in the relativities for gable and hip roofs. We computed the difference in average annual loss (no deductible) using Equation 3-1 with the empirical loss functions in Figure 3-15 and Figure 3-16 for a Tampa location. The gables have a 21% and a 14% increase in average annual loss over the hips for empirical loss functions from Figure 3-15 and Figure 3-16 respectively.

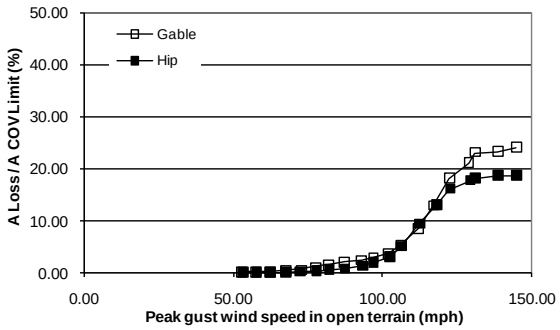


Figure 3-15. Smoothed Empirical Building Loss Functions for Gable and Hip Roof Shapes (Company A).

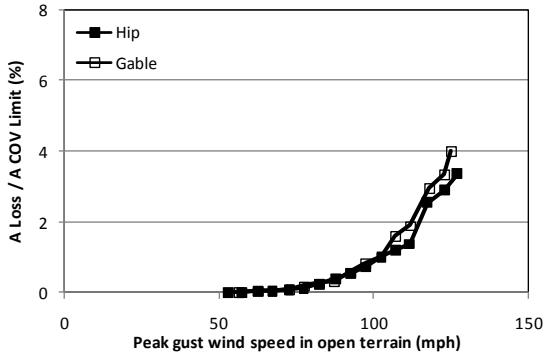


Figure 3-16. Smoothed Empirical Building Loss Functions for Gable and Hip Roof Shapes (Company F).

3.3.5 Roof Cover

From all the available datasets, only Companies A and F captured roof cover information in some way. For Company A, roof cover information was available for all policies in their dataset. Figure 3-17 illustrates the empirical loss functions for Company A for shingle and tile roof covers. Tile roof covers experience higher losses than shingles. The computed difference in average annual loss was about 29% for Tampa and 30% for Miami.

For Company F, roof cover information was available for only the inspected houses, which limits the size of the dataset.The available information only allowed us to classify whether the roof cover is FBC compliant or non-FBC. No distinction could be made for shingles or

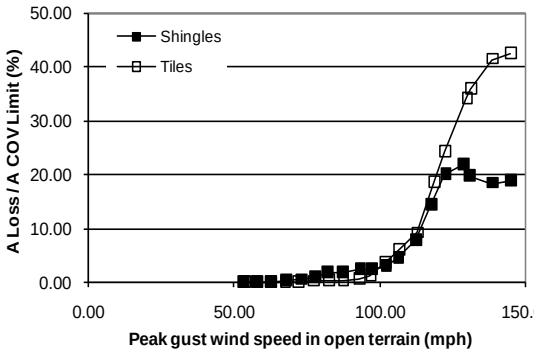


Figure 3-17. Smoothed Empirical Building Loss Functions for Shingle and Tile Roof Cover (Company A).

tiles. Figure 3-18 illustrates the empirical loss functions for FBC and non-FBC roof cover (Company F). We computed the difference in average annual loss (no deductible) using Equation 3-1 with the empirical loss functions in Figure 3-18 for a Tampa and Miami locations. The FBC roof covers have a 35% and 37% decrease in loss compared to the non-FBC roof covers for the Tampa and Miami locations, respectively.

3.3.6 Opening Protection

The opening protection construction feature was only captured by Companies A and F. This information was available only for a selected number of inspected policies, which limits the dataset used to derive empirical loss functions. Figure 3-19 presents empirical loss function for the no opening protection and (hurricane) opening protection cases. Both these function are jagged because of the lack of policies with opening protection information. Although, these empirical functions are based on a small number of houses, they still demonstrate that loss reduces dramatically as windspeed increases above 120 mph for a house protected with shutters.

We computed the difference in average annual loss (no deductible) using Equation 3-1 with the empirical loss functions in Figure 3-19 for a Tampa and Miami locations. The hurricane opening protection houses have a 37% and 38% decrease in loss compared to the houses with no opening protection for a Tampa and Miami locations respectively.

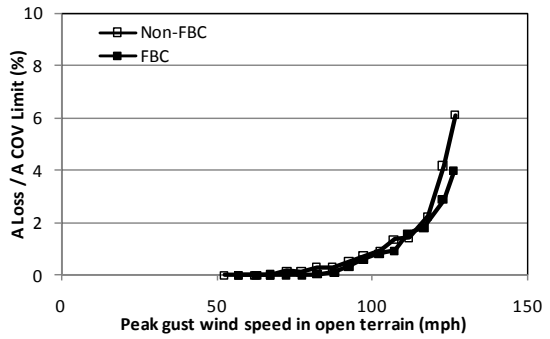


Figure 3-18. Smoothed Empirical Building Loss Functions for Non-FBC and FBC Roof Cover (Company F).

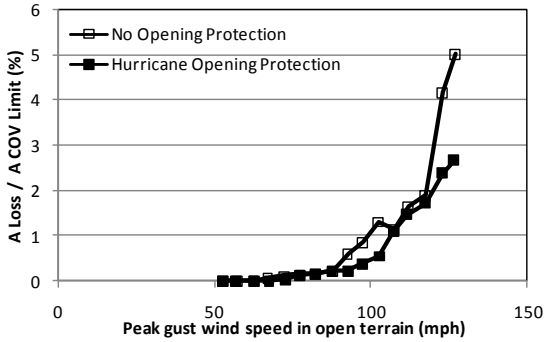


Figure 3-19. Smoothed Empirical Building Loss Functions for no opening protection and hurricane opening protection (Companies A & F).

3.3.7 Terrain

Terrain, or surface roughness, is an important building feature for wind loads. Buildings with open exposure experience significantly higher wind pressures than buildings that are protected by other obstructions, such as other buildings and trees. Terrain has been recognized as a design parameter in the U.S. standards for large buildings since at least the 1960s.

We were able to examine terrain for Company F dataset, which included several thousand inspected buildings with Terrain B and C included in the data. Recall, the loss 2002 relativity tables are different for Terrain B and C and hence the mitigation inspections require that Terrain be determined. [14]

[14] The terrain category from the inspections is a simplified terrain based on distance from the coast. It approximates terrain by classifying locations on barrier islands and within 1500 feet of the coast as Terrain C. All other inland locations are given Terrain B, except for HVHZ locations which are specified as Terrain C in the FBC. Hence, the terrain analysis is limited by these designations. One would expect that some of the Terrain B is actually C and some of the Terrain C (particularly those policies located in inland Dade and Broward Counties) is actually B.

The empirical loss functions for terrain are shown in Figure 3-20. We see that the Terrain B losses are reduced over Terrain C losses and that at higher windspeeds the difference appears to be increasing. The kink in the curves at 110 mph again reflects small amounts of data in those windspeed bins and the fact that the curves are only smoothed with a 3 point averaging process.

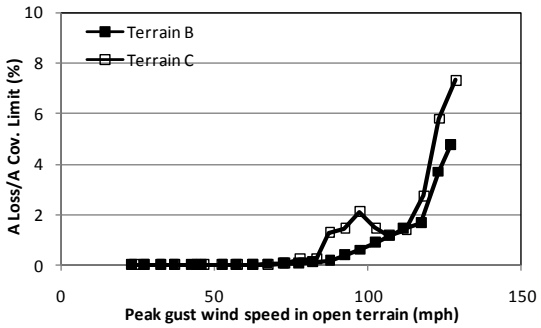


Figure 3-20. Empirical Loss Functions for Terrain B vs. Terrain C (Company F)

3.3.8 Frame vs. Masonry Wall Construction

Insurers have long used the masonry vs. frame construction classes for fire and windstorm loss rating purposes. As discussed in the 2002 loss relativity reports, wall construction is correlated to other important mitigation features, such as roof-to-wall connection, roof shape, roof cover, number of stories, etc. Unless these correlations are known for each data set, the quantification of frame vs. masonry as an independent mitigation feature remains difficult.

With this quantification we have analyzed the insurance data sets by wall construction. Figure 3-21 presents the smoothed empirical loss functions for frame and masonry construction types. For windspeeds <90 mph, there is no significant difference between the two curves. For windspeeds >90 mph, masonry construction is generally associated with lower losses.

Some of these datasets have information on other features. For example, Company A dataset shows that for one-story homes, masonry construction includes a hip roof 37% of the time, while frame construction includes a hip roof only 22% of the time. Obviously, the effect of hip vs. gable is inherently included in the masonry vs. frame loss data. Also, masonry tends to have fewer 2-story houses than frame construction. The Company A data shows that 14% of the frame construction is 2 story compared to only 7% of the masonry construction. The same data show that there are more tile roof covers for masonry construction (9%) than for frame construction (1%) in the Company A dataset. These statistics are included for discussion purposes only and are certainly not representative of the entire state nor of other insurers; however, they illustrate how other factors can bias a simple analysis of masonry vs. frame wall construction.

In the 2002 study, we included a 5% separate loss reduction effect for masonry wall construction over wood frame. That magnitude reflected the fact that the other mitigation features, such as roof-to-wall connection, roof shape, etc., were separately considered. In our analysis of wall strength, we did find that masonry walls are stronger and hence we were able to justify a rate differential for masonry walls.

Another factor in masonry wall construction may be that the replacement cost value of masonry wall houses is generally higher than for wood frame houses. Construction cost estimation data indicates that this difference, with every other house feature being equal, is about 5%. In addition, when we looked at the Coverage A limits, we found that masonry construction had about 5 to 20% higher limits than wood frame houses. Part of the reason that the insurance data shows reduced losses for masonry houses is that more of the value of the house is in the wall construction. Hence, for losses associated with windspeeds in which the differential wall strength is not important, the % Coverage A losses would be normalized by a larger Coverage A limit, thereby reducing the fraction of coverage A loss for masonry construction.

More work is needed in this area with larger and more complete data sets. Based on this analysis, a masonry rate differential appears warranted, and we will again use a separate 5% reduction for reinforced masonry walls vs. wood frame.

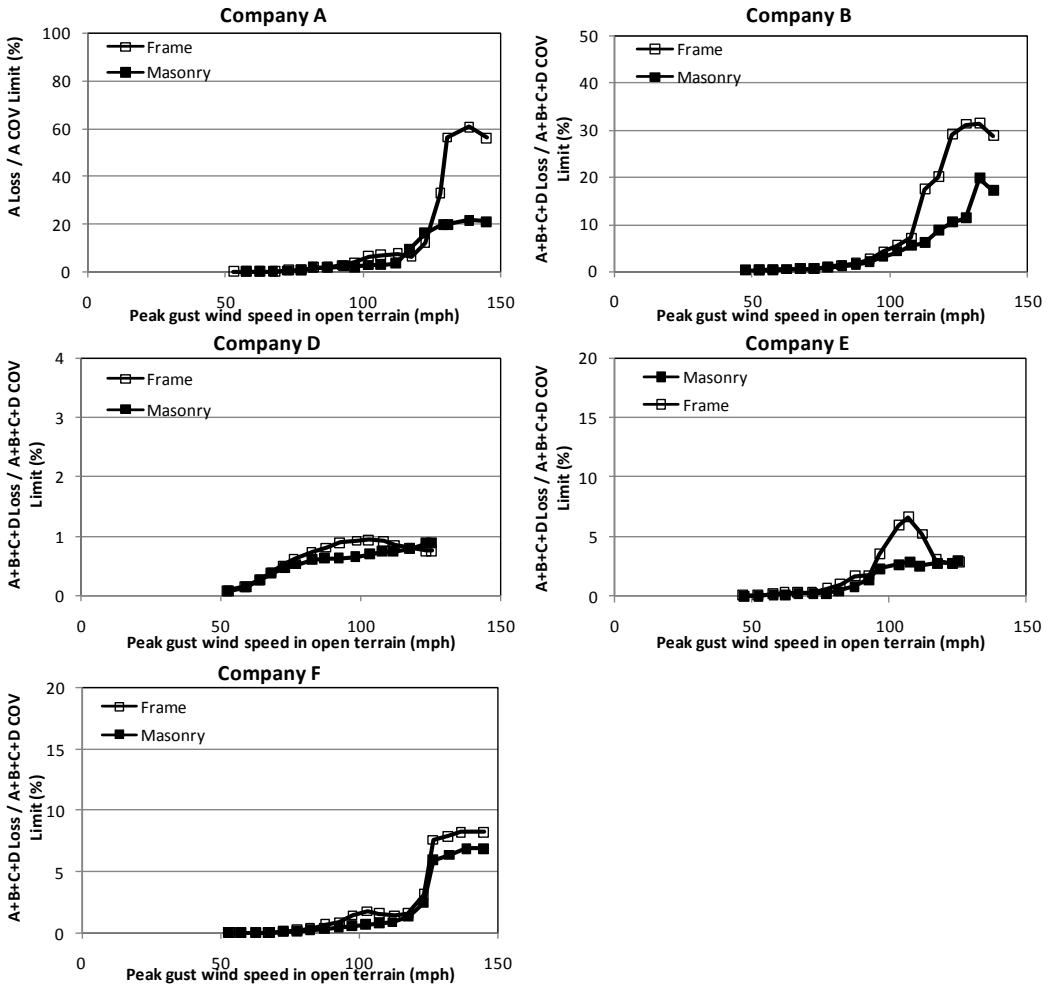


Figure 3-21. Smoothed Empirical Building Loss Functions for Frame and Masonry Construction Types.

3.3.9 Weak vs. Strong Houses (Multiple Feature Comparisons)

With the exception of pre- and post-FBC construction (which effectively compares many differences in building features), the previous analyses have focused on comparing one feature at a time. Exactly what the other features are for each house is unknown for many of the data sets and hence these single feature comparisons reflect some unknown averaging over other mitigation features. Clearly, one cannot add the individual effects together to get a combined mitigation effect. For example, individually, hips show about a 20% average reduction in loss over gables, FBC roof covers a 30% average reduction, shutters a 40% average reduction, and 1 stories a 30% average reduction over 2 stories. Adding these individual average effects produces a 120% reduction in loss, which is impossible. The individual average effects can't be added because the combined effects are nonlinear in their interaction. From the 2002 loss relativity tables, one can see that the effects of mitigating one feature are different depending on the remaining construction/mitigation features.

We have attempted to study the simultaneous effect of multiple mitigation features in the following manner. First, since the insurance data obtained for this project were not sufficient to analyze

individual building types with unique mitigation features (corresponding to a single cell in the loss relativity table), we grouped the data into "weak" and "strong" construction categories. We defined a weak house as a two-story house, with a gable roof shape, non-FBC roof cover and no opening protection while the strong house represented a one-story house, with a hip roof shape, FBC roof cover and hurricane opening protection. No distinction was made on roof-to-wall connection types, roof cover type, or roof-deck attachment. Hence, the houses were grouped over many cells in the loss relativity table and were classified according to our defined "weak and strong" groups. The definition of weak and strong houses was mainly governed by the small number of policies for which all these mitigation features were known. By grouping all houses with these features, we then had a sufficient amount of data to develop empirical loss functions for "weak" vs. "strong."

Figure 3-22 presents the empirical loss functions for a weak and a strong house (as defined above). We note that for peak gust windspeeds >70 mph, strong house performs better than weak houses. The difference between the two curves increases as the windspeed increases, which indicates that the mitigation features tend to make more of a difference at higher windspeeds, as expected. We computed the difference in average annual loss (no deductible) using Equation 3-1 with the empirical loss functions in Figure 3-22 for a Tampa and Miami location. The strong houses have a 65% and 62% decrease in loss compared to the weak houses for Tampa and Miami locations, respectively.

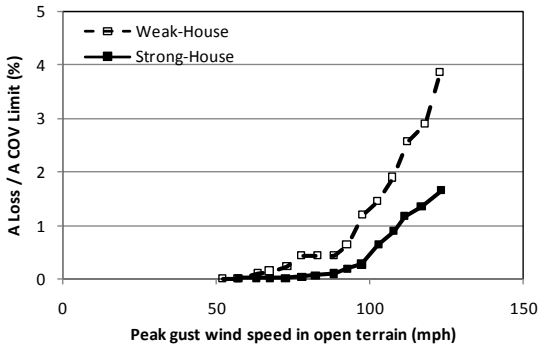


Figure 3-22. Smoothed Empirical Building Loss Functions for a Weak and Strong Houses (Companies A & F).

3.3.10 Summary of Insurance Policy Level Loss Analysis.

The analysis of policy level losses is significant in terms of validating the benefits of loss mitigation features. Table 3-2 presents a qualitative summary of these results.

We have also quantified the effects of mitigation and construction features by integrating the empirical loss functions according to Equation 3-1. We performed these integrations numerically using Monte Carlo Simulation. We simulated the hurricane hazard risk for each of the 18 Florida locations shown in Figure 3-22 and Table 2-4 (page 45). The results are average annual loss as a percentage of Coverage A. The difference in average annual loss is the loss reduction benefit of the mitigation or construction feature. Table 3-3 summarizes these results.

Table 3-2. Insurance Data Findings for Single-Family Homes.

Factor	*Finding*
Pre-FBC vs. Post-FBC	Post-FBC homes show significant loss reduction over pre-FBC homes.
Year of Construction	Losses reduce with year built, beginning in the mid-1990s.
Number of Stories	Two-story homes are more vulnerable than one-story homes.
Gable vs. Hip	The difference between loss features becomes significant for windspeeds >100 mph. On average, hip roofs result in about 20% lower loss than gable roofs.
Shingles vs. Tiles	For windspeeds > 100 mph, there is a discernable reduction in loss for shingle roof covers.
Opening Protection	Homes with opening protection have notably reduced losses.
Frame vs. Masonry	Masonry homes show loss reduction, but the data is confounded by other construction characteristics, that are correlated to wall construction type.
Terrain	Houses located in Terrain B have reduced losses over houses in Terrain C.
Weak vs. Strong	Houses with several mitigation features experience significant loss reduction.

Table 3-3. Results of Integration of the Empirical Loss Functions for Each Florida Location.

Case Number	Change in Mitigation or Construction Feature	Ins. Co.	Percent Reduction by Simulated Location Point																		Average % Reduction	Std. Dev.
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
1	Gable to Hip-A	A	34	28	36	30	26	24	31	25	34	23	30	21	22	22	20	19	19	21	25.9	5.5
2	Gable to Hip-F	F	14	14	12	13	13	14	13	14	14	15	13	15	15	14	15	15	15	15	14.1	0.8
3	Tiles to Shingles	A	22	24	18	24	24	27	25	29	24	29	23	34	32	32	34	34	35	39	28.3	5.7
4	Non-FBC to FBC Roof Cover	F	45	38	46	40	36	35	41	35	44	35	40	33	34	34	32	32	32	34	36.9	4.6
5	No Shutters to Shutters	F	40	38	40	38	37	38	39	38	40	38	38	39	39	38	38	39	39	40	38.7	0.9
6	Weak to Strong	F	73	69	74	71	68	67	71	67	73	66	70	64	64	65	63	62	62	63	67.3	3.9
7	Weak to Strong- No Cap	F	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	52	53	52	53.0	0.2
8	Pre-FBC 2002 to Post-FBC	A	87	87	89	88	87	86	86	86	87	84	87	82	83	84	82	82	82	82	85.0	2.5
9	2 Story to 1 Story	A	33	28	32	27	28	29	28	30	35	31	27	34	32	32	33	34	34	34	31.2	2.8
10	Terrain C to Terrain B	F	56	52	58	54	52	49	53	50	56	47	53	44	45	46	43	43	42	42	49.1	5.3

From Table 3-3, we see that the effect of roof shape for Company A is a 26% reduction in loss, when averaged over all 18 locations, whereas the effect of roof shape for Company F is a 14% reduction. These differences reflect the empirical nature of the data and the fact that other important mitigation features are inherently built into these one at a time comparisons. There is also variation from point to point, which reflects the differences in hurricane risk at each location. The point-to-point variation can be seen in Figure 3-23. The variation is due to the shape of the loss functions and the risk of different magnitudes of hurricane winds in different parts of the state. Some of these empirical functions produce a decreasing effect of loss reduction with increasing hurricane risk, while some are flat, and others show a slight increase in loss reduction with increasing hurricane risk.

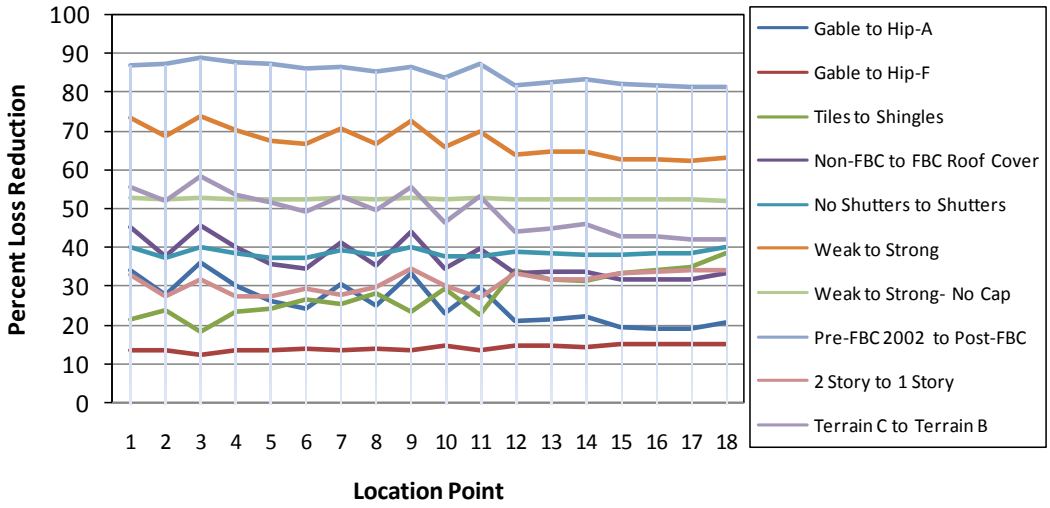


Figure 3-23. Statewide Variation of Loss Reduction Using Empirical Loss Functions.

The remaining cases in Table 3-3 show fairly significant empirical estimates of loss reduction for tile to shingle roof covers, FBC roof covers, shutters, strong houses, post-FBC construction, and 1-story homes. The largest mean effect is for the post-FBC construction, which shows an average 85% loss reduction over pre-FBC construction.[15]

[15] Based on the windspeed ranges in these datasets, we believe that a notable portion of this loss reduction is related to roof cover, and in particular the improved roof covers which were just a few years old at the time of these hurricanes. However, we also expect that at very high windspeeds, which would tend to stress the envelope connections and produce high levels of wind-borne debris, that there would still remain significant differences in pre- and post-FBC due to the mitigation features required of post-FBC construction.

We note that the effect of horizontal capping of the empirical loss functions at high windspeeds vs. extrapolating the empirical loss functions and capping them at 100% is illustrated by Case 7 in Table 3-1. When we extrapolated the function, the effect was to reduce the loss reduction effect from 67% to 53% for the "weak to strong" case. We also analyzed Case 8 (pre-FBC vs. post-FBC) by extrapolating the function instead of capping it. In this case, the average loss reduction over all locations was 84% (instead of 85% when capped) with a range of 75% to 90%.

The average percentages of loss reduction in Table 3-3 are shown as a bar chart in Figure 3-24. For comparison purposes, we have used results from the 2002 loss relativity studies to compute model predicted loss reduction. The red bars in Figure 3-24 show the estimated loss reduction for 2% deductible from the 2002 studies (ARA, 2002a). These estimates have been generated by averaging over the appropriate cells for the Terrain B results. For example, the gable to hip reduction was obtained by averaging over the "other' roof shape column with no secondary water resistance and comparing that to the hip roof shape average for no secondary water resistance. Those averages indicate a 33% loss reduction. For the tile-to-shingle, 2 story-to-1 story, and Terrain C to Terrain B, we used the relativities from Twisdale, et al. (2007), which were based on an insurance study performed in 2002. The 2002 results for terrain were developed by comparing loss costs averaged over all modeled buildings for Points 11 and 12 (120 mph), Points 21 and 22 (140 mph), and Points 25 and 26 (150 mph) from Table 2-2 in ARA (2002a).

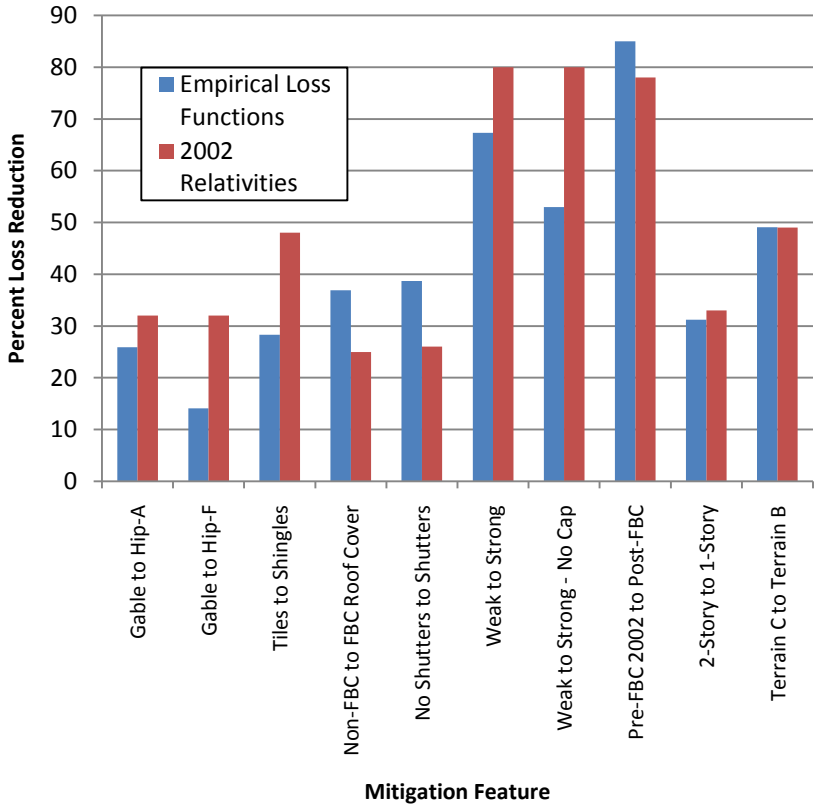


Figure 3-24. Average Loss Reduction Using Empirical Loss Functions with Comparison to 2002 Loss Reduction Estimate.

Overall, the 2002 modeled loss reductions are in general agreement with the insurance data analysis performed in this study. The amount and quality of the data do not permit validation of every building mitigation feature; but we believe that the differences noted in this analysis help provide

confidence in the modeling approach used to quantify loss relativities. It is important to realize that the majority of the (insurance data derived) empirical loss functions are based only on Coverage A losses and do not include other structures such as fences, storage sheds, gazebos, which are generally covered under Coverage B, contents (Coverage C), or loss of use (Coverage D). Also, there was only one Florida hurricane with winds over 130 mph (Charley). Hence, some of the empirical loss functions do not exceed 10% loss fractions for the windspeeds for which loss data was available. However, the results are significant and tend to support the overall magnitudes of loss reduction that were estimated in the 2002 studies.

3.4 Insurance Claim Folder Analysis

The primary focus of the insurance claim folder analysis was to identify causes and extents of losses, particularly losses not associated with failure of the building envelope. The hurricanes that struck Florida in 2004 and 2005 provide recent data on features of buildings that cause losses during hurricanes that are not necessarily correlated with damage to the building envelope. Among these items are: wind-driven water causing interior damage; losses resulting from damage to exterior elements of homes; losses resulting from tree removal and tree debris removal; and losses resulting from damage to attached and detached structures. The lessons learned from this analysis have been applied to our modeling updates of hurricane damage and loss to individual structures.

The claim folder review has been primarily focused on the adjusting practice for the following non-structural envelope related losses:

1. Losses in low to mid-level winds.
2. Losses from exterior portions of homes located outside of the building envelope.
3. Losses to interior components due to water leakage when the building envelope (windows, doors, roof covering, and roof sheathing) is not breached.
4. Losses from tree removal and tree debris removal.
5. Losses from damage from roof covering.

The following subsections summarize the findings of this review.

3.4.1 Background on Claim Folders

Four different insurance companies provided copies of 1,905 single- and multiple-family home claim folders from Hurricanes Charley (2004), Frances (2004), Ivan (2004), and Wilma (2005). Table 3-4 summarizes the total number of single- and multiple-family claim folders received and reviewed.

Table 3-4. Count of claim folders received and reviewed by storm

Storm	*Type*	*Count of Claims*	
		Reviewed	*Received*
Charley	Single Family	231	231
	Multi- Family	86	90
Frances	Single Family	129	638
	Multi- Family	87	180
Ivan	Single Family	169	181
	Multi- Family	88	97
Wilma	Single Family	230	315
	Multi- Family	89	173
Total Reviewed		**1109**	**1905**

The claims received from the four insurers varied widely in their level of organization and completeness. Claim folders provided by two of the insurers were generally complete and easy to follow. These claim folders generally included clear, dated summary sheets showing losses by coverage type, complete repair estimates, claims adjuster logs, and black and white copies of photos documenting the damage. The only consistent deficiency in these claims for the purpose of this analysis was the generally poor quality of the photos that made it difficult to discern the damage they were documenting. Nearly all of the claim folders provided by these two insurers were reviewed for this study.

The claim folders received from the other two insurers were decidedly more difficult to understand as a result of their lack of organization. These folders rarely included summaries of loss by coverage type and claims adjuster logs. The lack of clear summaries and logs made it difficult to discern whether or not the estimates provided represented the total loss and made it nearly impossible to definitively allocate the losses by coverage type. On the other hand, the claim folders from these insurers had higher quality color photos than the photos from the other two insurers.

A limited number of claims for multi-family homes were reviewed because we rarely received enough information from any of the insurers to develop a complete picture of the loss to an individual building. We received some claim folders for master/condo association policies and some for unit owner policies, however these claims were generally not from the same buildings. In other words, we knew about damage to the building shell and common areas when we had the master policy claim, and an individual unit in an unknown building when we had a unit owner claim. To rectify this situation, we requested additional multi-family claims from insurers that could provide both the master policy claim and a number of unit owner claims from the same building. However, due to schedule constraints on this project, we were not able to complete the analysis of this new information. Consequently, the analysis of the data extracted from the claim folders reviewed is focused on single family homes.

3.4.2 Claim Folder Review Process

The claims folder review process consisted of extracting data from the claim folders and inputting the information into a MS-Access database. Following data extraction, each claim location was geocoded (assigned a latitude-longitude location) and the wind speed for each site (based on the storm causing loss) was determined using ARA's hurricane track and wind field model.

3.4.2.1 Data Extraction

Data was extracted from the claim folders in a standard, objective manner that broke each claim down by its component parts so that they could be reassembled during the data analysis process. This approach allowed for a greater flexibility when analyzing the data extracted from the claim folders. The basic process that we followed is described below.

First, general policy information including address, dwelling type, hurricane, year built, and policy limits and deductibles were recorded. Next, a breakdown of the total ground-up loss by coverage was captured on a replacement cost value (RCV), actual cash value (ACV), and gross claim (ACV plus recoverable depreciation) basis.

Information was then compiled on several sections of the dwelling including the roof (roof cover, sheathing, soffits, vents, and framing), fenestrations (windows, doors, skylights, garage doors), walls (covering, structure, and accessories), built-in structures (screened and unscreened porches and carports under the main roof), attached structures, and detached structures. Three basic pieces of information on each of these areas were collected; a physical description of the component, the observable physical damage to the component, and the cost to restore the component to the pre-storm condition.

Loss to interiors was classified by the level of restoration effort required (none, cleaning, painting, repair, and/or replace) and the total cost of repairs to the interior portion of the building. Other losses including tree removal, food spoilage, debris removal, temporary repairs, and adjustments to base costs were also recorded as separate items.

Table 3-5 contains a complete list of the building components that were used to classify the description, damage, and loss data extracted from the claim folders. The table also includes the highest level category that was used to group various building components for the data analysis.

Table 3-5. Building Components and Corresponding Analysis Categories for Claim Folder Analysis.

Component	Category
Roof Covering	Roof Cover
Single Doors	Fenestrations
Single Garage Doors	Fenestrations
Skylights	Fenestrations
Sliding Glass Doors	Fenestrations
Double Doors	Fenestrations
Double Garage Doors	Fenestrations
Windows	Fenestrations
Built in Carport	Exterior Accessories
Roof Vents	Exterior Accessories
Built in Screen Porch	Exterior Accessories
Built in Unscreened Porch	Exterior Accessories
Wall Accessories	Exterior Accessories
Wall Covering	Exterior Accessories
Interiors	Interior
Roof Framing	Interior
Wall Structure	Interior

Component	Category
Soffits	Soffits
Roof Sheathing	Roof Deck
Attached Screen Enclosure	Attached Screen Enclosures
Attached Carport	Other Attached Structures
Attached Other	Other Attached Structures
Attached Storage Shed	Other Attached Structures
Detached Carport	Detached Structures
Detached Garage	Detached Structures
Detached Other	Detached Structures
Detached Screen Enclosure	Detached Structures
Detached Storage Shed	Detached Structures
Fences & other APS	Detached Structures
Trees	Tree and Tree Debris Removal
Debris Removal	Debris & Temp Repair
Temporary Repairs	Debris & Temp Repair
Food Spoilage	Food Spoilage
Adjustments to Base Cost	Adjustments

Several of the categories identified in Table 3-5 correspond directly to the way in which the HURLOSS hurricane damage-to-loss model works to build up the total dollar value of loss in much the same way that a loss adjuster would estimate the repair costs. The HURLOSS damage-to-loss model estimates the actual cost to repair components of the building envelope that are damaged directly by the wind. This includes the roof cover, roof deck, fenestrations and soffits. Interior damage is subsequently estimated based on empirical relationships developed from previous insurance claim folder reviews, structure subassembly costs, and engineering judgment. Empirical relationships are also used to estimate loss to other building components and debris removal expenses.

3.4.2.2 Wind Speed Estimation

Each of the 1,109 claim locations was assigned a latitude and longitude. A total of 912 locations were geocoded to the exact street address, 9 to the street level, 30 to the city center level, and 158 to the zip code level (population centroid). It should be noted that all claim folders from one of the insurers (135) contained only the zip code for the claim location.

With the latitude and longitude positions known, the peak gust wind speed in open terrain was determined for each location using the ARA hurricane wind fields developed for each hurricane. The hurricane track and wind field models used to estimate wind speeds at each loss location is discussed in Appendix B. The locations and wind speeds calculated for each location are shown in Figure 3-25.

3.4.3 Claim Folder Data Overview

Individual component losses were re-combined by loss category to evaluate their relative contributions to the overall losses in the claims. These losses were then normalized by the total direct loss to the building. The direct loss to the building is defined as the total replacement cost value of all of the components classified in the roof cover, fenestrations, roof deck, soffits, interior, and exterior accessories categories. Following normalization, the average loss by wind speed range was then computed for each of the loss categories.

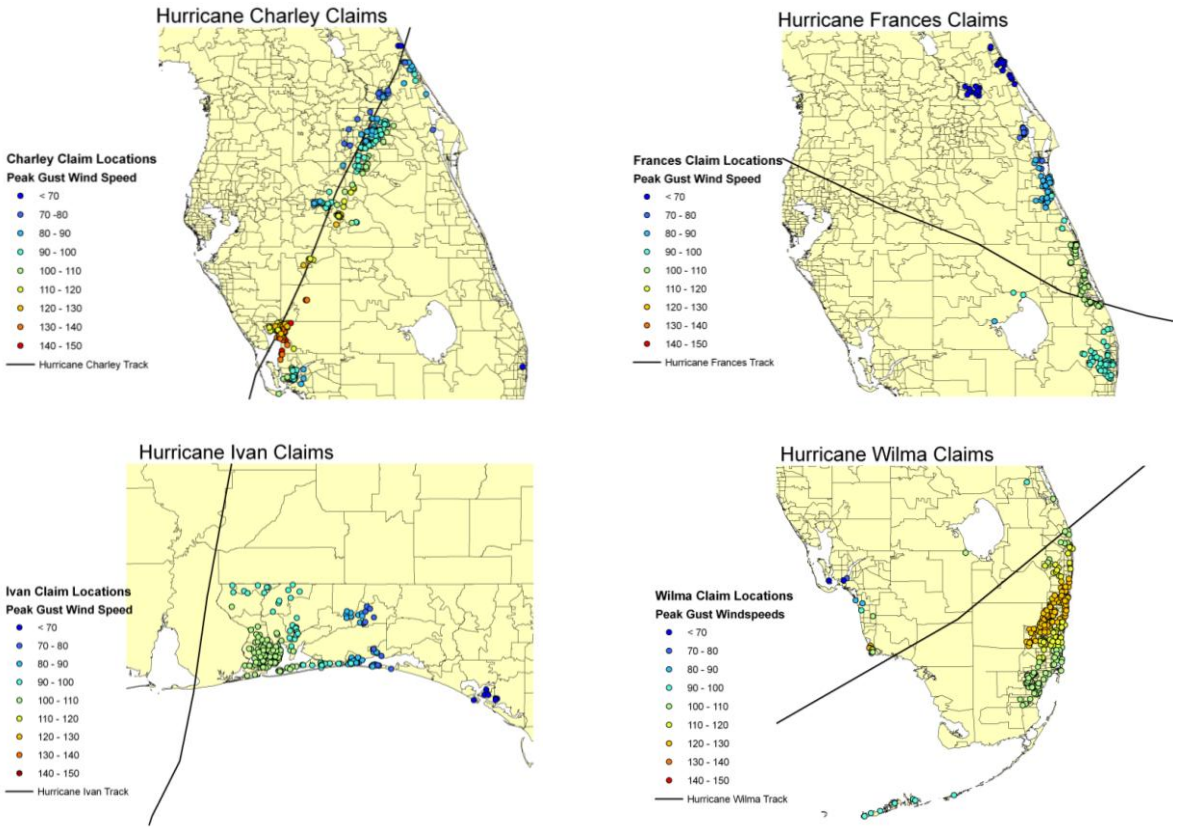


Figure 3-25. Claim Folder Locations and Peak Gust Wind Speed by Hurricane.

Figure 3-26 shows the average contribution to the building loss for each of the building related components. As the figure shows, roof cover loss is dominating the losses at all wind speeds and represents about half of the total loss to a building for these datasets. The figure also shows that exterior accessories represent about 5 to 10 percent of the total building loss. This result is significant because these are items that will be damaged directly by wind and not necessarily dependant on the performance of the building envelope. Note that Figure 3-26 shows normalized loss by windspeed bin, and does not contain information on how the severity of the loss increases with windspeed.

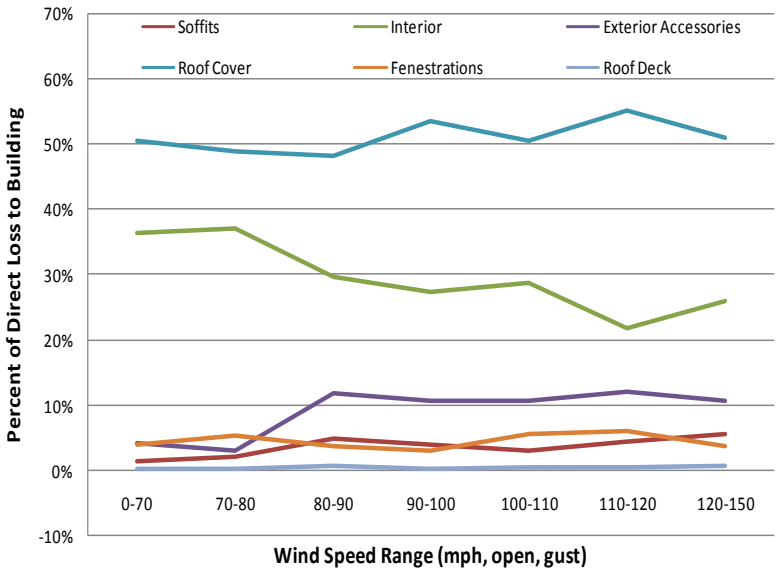


Figure 3-26. Average Loss Contribution from Building Components by Windspeed Bin.

Figure 3-27 shows the average losses from non-building components, also normalized to the total direct loss to the building. From this figure, we see that attached screen enclosures are a very significant source of loss. We also see in the figure that tree and tree debris removal costs can contribute up to an additional 50% to the direct building loss at certain windspeeds. Figure 3-27 also shows that losses from general debris removal and temporary repairs play a much more minor role.

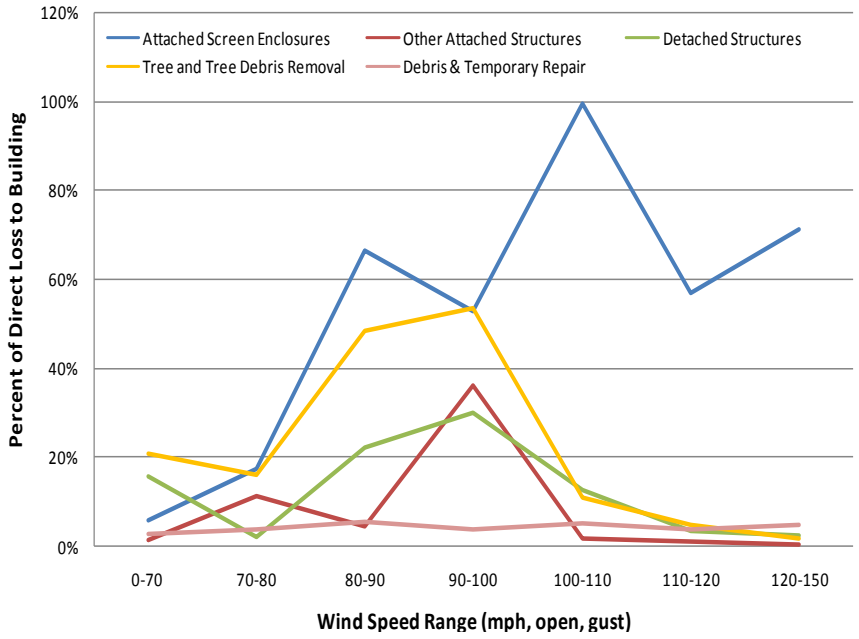


Figure 3-27. Average Loss Contribution from Non-Building Components by Windspeed Bin.

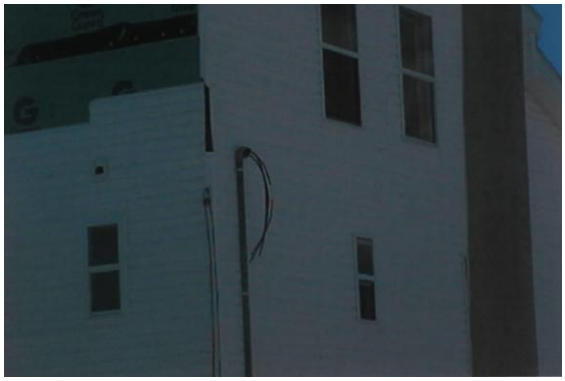
3.4.4 Exterior Accessories

Exterior accessories are defined as those components of a building that are located on the exterior of the building, but are not considered to be a part of the building envelope. As a part of the claim folder data, exterior accessories included built-in carports and porches (under the main roof of the building), roof vents, wall coverings, exterior trim including decorative shutters and fascia, and wall accessories including exterior lights, and electrical, plumbing, and exterior HVAC system components. Figure 3-28 includes example photos taken from claim folders of damaged items that were included in the exterior accessories category. Because these components of the building are exposed directly to the weather, their performance is generally not dependent on the structural performance of the building envelope.[16]

Figure 3-29 shows that exterior accessory loss as a percent of building (coverage A) value increases with wind speed and can represent up to about 11% of the total building value at the higher wind speeds. The relative value of exterior accessories was also calculated based on per square foot costs from RS Means Residential Cost Data 2008 (RS Means 2008a) and was found to be 12% on average for single family homes.

These data were used to develop a new function in the damage-to-loss model to account for losses to exterior accessories and is discussed in Section 3.6.1.6.

[16] Major or catastrophic failure of the exterior walls of the building would obviously induce damage to exterior accessories. However, the building would be a total loss at that point anyway.



(a) Power Mast and Drip Wire



(b) Exterior Trim



(c) Exterior Light Fixtures



(d) Exterior Components of the Water System

Figure 3-28. Examples of Damage to Exterior Accessories.

3.4.5 Interior Loss without Building Envelope Damage

Sixteen of the single family home claims reviewed included some measure of loss to interior components without any loss to the building envelope. These losses are most likely present in several other cases (for example, some roof cover lost, but no apparent roof leak), but cannot be separated out in a claim folder review. This distinction would have to be determined when the loss was initially inspected.

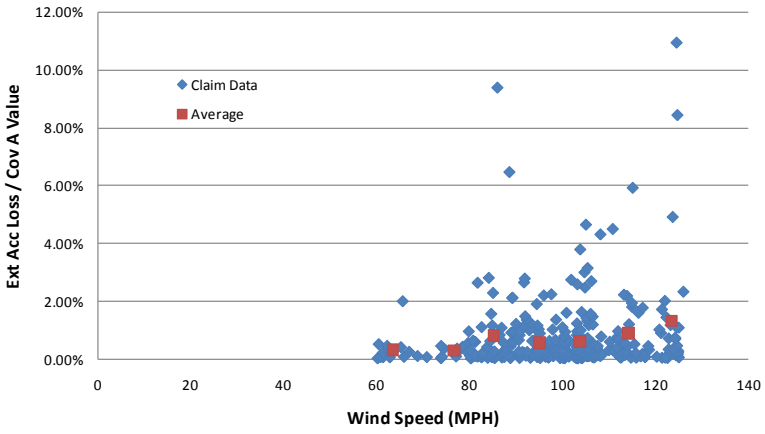


Figure 3-29. Exterior Accessory Loss vs. Windspeed.

Fourteen of the 16 claim folders had losses below the 2% deductible when taken by themselves. In some cases, policyholders may not file claims for these low level losses; however, most of these cases also showed losses to attached pool enclosures or appurtenant structures. When these other losses are considered, the total loss is then above the deductible and then the insurer becomes responsible for paying for these non-envelope based losses.

To illustrate this point, 107 claims were identified that had a 2% deductible and would have had a claim less than the deductible had the loss from attached and detached structures not been included in the loss. The losses from these claims are plotted in Figure 3-30 with and without the attached and detached structure losses. By including the attached and detached structure losses, 51 of the 107 (48%) claims become larger than the deductible. This effect is an important finding because the various coverages on a typical homeowner's insurance policy generally share a common deductible. The relativities presented in this study were computed assuming that homes did not have any attached structures or any coverage for appurtenant structures. As such, the value for these items are set to zero for the analysis; however, if these structures are present and do not have a separate deductible, then any loss to these structures is likely to consume a large portion or all of the deductible, resulting in any minor damage to the building producing losses that are above the deductible.

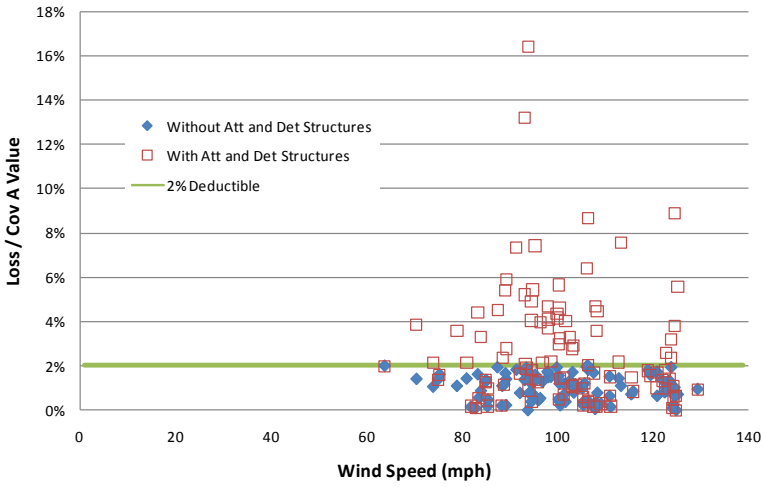


Figure 3-30. Total Loss for Claims Less than the 2% Deductible.

This problem will not go away if insurers just place lower limits, or sublimits, on the attached and appurtenant (detached) structures. If these other structures experience losses greater than their coverage limits, then the remainder of the value that the policyholder is responsible for will still be credited to the policy deductible through the practice of deductible absorption. In order to reduce this effect, and for the proper use of the relativities published in this report, all coverage for structures other than the main dwelling should have a separate deductible. The loss relativities developed in Section 4 do not assume any contribution from attached or detached structuresto the deductible.

The damage model was changed to allow water leakage into a building through windows and doors that have not been broken by the wind or debris. This change to the damage model is discussed in Section 3.6.1.3 and is propagated through to the damage-to-loss model as described in Section 3.6.2.

3.4.6 Tree Removal

Claim folders that included the effects of trees falling on homes or other insured structures were identified during the claim folder review process by noting whether or not the direct physical damage resulted from tree fall and whether or not payments were made for either removal of trees from covered property or tree debris removal. In cases where trees did fall on homes, it was difficult to distinguish the damage caused by the tree from damage that was caused directly by the wind. This situation was also complicated by the fact that the trees were commonly removed from the dwellings before the claim was inspected and photographed. As a result, the only photographs documenting the damage generally consist of a blue tarp covering the edge of the roof and a nearby stump on the ground.

The costs for tree removal and tree debris removal were, on the other hand, easily separated from other costs in the claim folder estimates (see Figure 3-31). As demonstrated in Section 3.4.3, these costs can represent a notable amount to a claim on an individual building. These data were used to develop a new function in the damage-to-loss model to account for losses due to tree removal and tree debris removal as discussed in Section 3.6.2.

3.4.7 Roof Covering

Section 3.4.3 revealed that roof covering related loss dominates the overall loss to buildings for the claim folders reviewed.[17] Given the relative importance of the roof covering loss, the roof covering claims were analyzed in greater detail. To this end, we used the claim folder data to answer questions about roof covering repair versus replacement to ensure that we are modeling the relationship between roof cover damage and roof cover loss appropriately.

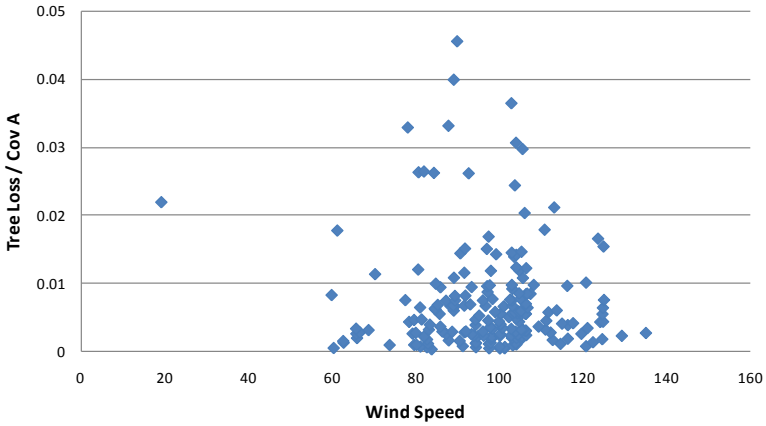


Figure 3-31. Tree removal and tree debris removal loss as a percent of building value vs. windspeed

Table 3-6 shows average roof covering repair and replacement costs and minimum roof covering costs from the claims reviewed for shingle and tile roofs. The cost for roofing repair is generally quoted on a per shingle or per tile basis as opposed to a per square (1 square = 100 square feet) basis. For comparison in this table, the per shingle and per tile prices from the claims were converted to per square values by multiplying the per unit prices by the average number of pieces per square for each roof covering type. The multipliers used were 78 shingles per square and 150 tiles per square.

Table 3-6. Shingle and Tile Roof Claim Average Costs Data.

	Repair ($/Sq)	*Replace ($/Sq)*	*Repair/Replace Ratio*	*Minimum ($) Charge*
Shingle Roof	$849	$273	3.1	$425
Tile Roof	$4,356	$763	5.9	$553

Note that the unit cost to repair roofs is much larger than the unit cost to replace a roof. This fact is due primarily to the increased complexity of repairing the damage to a roof without damaging the undamaged areas. Also, repairing tile roofs is generally more difficult that repairing shingle roofs because of the brittle nature of the material and the difficulty of working on a tile roof.

The information in Table 3-6 sheds light on the cost implications of repairing versus replacing a roof. These cost differences certainly play a role in the claim adjuster's decision to repair or replace a roof which has been damaged by a hurricane. In addition to the cost implications, a number of other factors were observed during the course of the claim folder review including the roof condition, the perception of damage extent, and product matching issues.

Figure 3-32 shows a shingle roof that has failed a brittleness test. This test was commonly observed in the claim folders reviewed for roofs that had minimal levels of damage in order to determine the reparability of a shingle roof. If the undamaged shingles remain pliable, then a roofer should be able to complete a repair by only replacing individual shingles where needed. However, if an undamaged shingle cracks, breaks, or tears when lifted, then an attempted repair of the roof would likely result in further damage. This being said, it becomes clear that the threshold for complete roof replacement for a shingle roof in poor, brittle condition is any damage at all and the only time that a shingle roof will be repaired is when it is still in good enough condition to survive the repair process.

[17] Most of the claim folder losses were for winds ≤ 120 mph. At higher winds, more building envelope failures would likely occur and roof cover losses, as a fraction of the total loss, would be expected to reduce.

Perception of damage is also another factor in determining a damage threshold for the complete replacement of a roof. Figure 3-33 contains four pictures of a shingle roof on a home that the adjuster has noted experienced "damage to more than 70% of the roof". This conclusion is likely based on the fact that the damage is spread over a vast portion of the roof, and not that 70% of the roof is actually missing or physically damaged. If all of the damage were confined to a single portion of the roof, it would be much easier to accurately assess the overall percentage damaged and the total percentage reported would likely have been lower than 70%. In this particular case, the actual percent of the roof cover damaged makes little difference in the eventual claim because the roof has been extensively damaged and is in obvious need of replacement. However, it does provide an example of how one's perception of damage level can be affected by the scattered nature of the damage. And this perception can have a dramatic effect on the repair versus replacement decision when a minimal amount of damage is localized or scattered around a roof surface. Overall, this example shows us that the decision to repair or replace a roof is complicated and subjective.

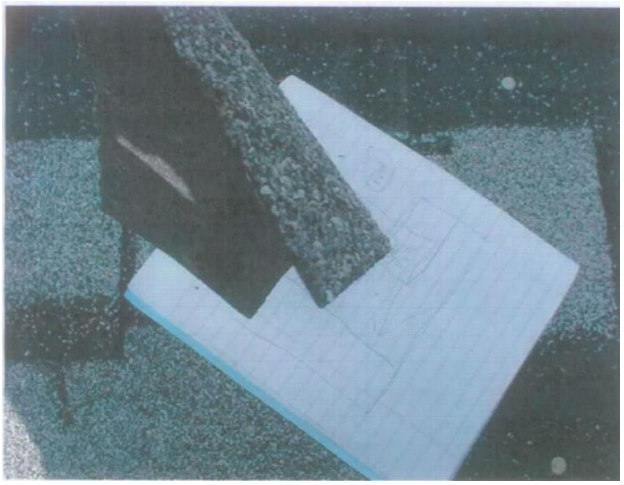


Figure 3-32. Example of Shingle Roof Failing a Brittleness Test to Warrant Complete Replacement.



Figure 3-33. Shingle Loss and Perception of Damage Extent.

Product matching was also observed to be a complicating factor in the repair versus replace decision. Product matching can be exacting for tile roofs where matching the profile or curve of the existing tile is necessary in order to keep the roof weather-tight. Matching of colors becomes more of a problem as the roof cover ages; however, color matches may not be a requirement in many insurance policies.

3.4.8 Soffit Damage and Loss

Review of low-windspeed claims identified in the analysis show that soffits are generally damaged and lead to additional interior losses before the components that are traditionally considered as components of the building envelope (roof cover, roof sheathing and fenestrations).

The claims reviewed in this project have clearly illustrated that failed soffits lead to water entering attics and causing losses due to wet attic insulation and water stained or collapsed ceilings. Quantification of these interior losses was not possible with the available claim data.

3.4.9 Attached and Detached Structures

A total of 528 claim folders[18] from Hurricanes Charley and Wilma from a single insurer were analyzed as a part of an OIR study in 2007 (Twisdale, et al., 2007). The analysis presented in the project report indicates that exterior structures are damaged at lower windspeeds than the main dwelling structures.

Table 3-7 was taken directly from the 2007 report (Twisdale, et al., 2007) and shows how exterior structure claims contribute to the claims reviewed. The exterior structure losses are normalized by the total claim dollars in the top half of the table and by the Coverage A losses in the bottom half of the table. These results indicate that exterior structures comprised 28% of the total claims in Hurricane Wilma for single-family homes. This result indicates that exterior structures represented a large percentage of the claims in a relatively modest hurricane. For Hurricane Charley, the exterior structure claims were much less, about 8% of the total claims. Note that the higher windspeeds in Hurricane Charley produced much more damage to the primary dwelling structures and hence the contribution of exterior structures is a lower percentage of the total amount paid. The numbers for Hurricane Wilma are especially remarkable because the survey component of the exterior structure project showed that, on average, exterior structures represent approximately 10% of the of the insured value of the structure.

Table 3-7. Exterior Structure Claim as Percent of Total Claim.

Normalizing Value	*Hurricane*	*Mobile Home*	*Single-family*
Total Claim	Wilma	21.03%	28.37%
	Charley	27.24%	8.16%
Coverage A	Wilma	22.11%	33.32%
	Charley	28.16%	9.30%

The impact of attached and detached structures on loss costs is significant and insurance companies should not apply wind mitigation rate differentials to any portion of the wind premium that covers the loss costs or deductible-impact from these types of structures.

3.4.10 Insurance Claim Folder Analysis Summary

Our insurance claim folder analysis focused on identifying and quantifying low level sources of insured loss that affect hurricane insurance claims for windspeeds in the 80 to 120 mph range. Basically, we looked for all types of losses not associated with modeled building envelope components and loss mitigation features. These types of losses were discovered in building components that are damaged

[18] These claim folders are separate from the 1,109 reviewed for this study.

independently of the building envelope components. We also found that roof covering losses were driven by complexities of the claim adjusting and repair process for given levels of damage.

The sources of loss that are not directly related to damage to the building envelope were identified and quantified. Loss data developed from the claim folder review have been used to update the modeling of low-end losses for the following areas:

- Exterior accessory loss
- Interior loss without building envelope damage
- Secondary effect of attached and detached structures
- Tree removal and tree debris removal loss

Details of the adjusting process for determining repair versus replacement for roof cover damage were discovered and have been incorporated into the loss relativity modeling. Lessons learned about roof covering losses and the way that they are adjusted were also used to update the damage-to-loss model and include:

- Minimum charges for roof cover replacement
- Higher unit costs for roof cover repair versus roof cover replacement
- Roof condition

The negative influence of attached and detached structures affecting a common deductible was also evaluated. Attached and detached structures should have separate coverage and separate deductibles form the dwelling. This separation approach has been assumed in this loss relativity study.

3.5 Physical Damage Data

The Florida hurricanes of 2004 and 2005 provided an opportunity to assess physical damage through surveys of damaged buildings. Several organizations performed damage surveys, including University of Florida, Florida Department of Community Affairs, FEMA, and Applied Research Associates. Two of these surveys are summarized here.

3.5.1 University of Florida (UF) Surveys

The UF survey (Gurley et al, 2006) focused on a statistical comparison of pre-FBC houses (built between 1994 and 2001 to the Standard Building Code and homes built after 2002 to the FBC. The survey consistent of 195 homes (126 in Charley, 36 in Ivan, and 33 in Frances/ Jeanne). Some of the key findings of the study were:

- The use of window protection reduced window damage by 65%. Homes in tile neighborhoods were more likely by a factor of two to experience window damage.
- There was an increased likelihood of soffit damage with increasing age of structure. About 30% of the pre-FBC homes reported soffit damage, compared to 24% of the post-FBC 2001 homes. The severity of damage was higher with older homes (about 40% for pre-FBC and 24% for post-FBC.
- Roof cover (shingle and tile) damage was much more extensive for pre FBC-houses and increased with age.
- Water penetration was reported by the homeowner for about ½ of the homes and there was little difference in pre-FBC and post-FBC houses. About 15% of the homeowners reported water leaks around doors, about 20% reported water leaks around windows, and about 5% reported leaks near exterior walls. Slightly more than 20% reported ceiling leaks.

There are many plots and data comparisons in the report beyond these basic conclusions. Overall, the research indicates that shutters make a big difference; soffit performance is an important mitigation feature; tiles are a significant source of missiles; age effects are important in roof cover performance; and water penetration through openings remains an area for building code improvement.

3.5.2 ARA Survey of Hurricane Charley Damage

ARA surveyed single-family homes, mobile homes, and commercial buildings following Hurricane Charley. These surveys were conducted by ARA engineers within the first week after the storm. Some of the key results of the single-family home survey are discussed in the following paragraphs.

ARA surveyed 370 homes in 14 locations in the Charlotte Harbor area, as illustrated in Figure 3-34. These areas experienced high windspeeds (130 to 150 mph, see Appendix B) and significant damage, as illustrated in Figure 3-35, and hence one would expect discernable differences in the performance of houses with and without wind loss mitigation features. These surveys collected data on the building envelope performance, including: year built, number of stories,oof shape, roof cover type, tile roof attachment (nails/screws *vs*. mortar), % roof cover damaged, sheathing type, % sheathing damaged, windows (number, number protected, number damaged), single doors (number, number protected, number damaged), double doors (number, number protected, number damaged), sliding doors (number, number protected, on observed damage. The data were also grouped into predominate roof cover within a neighborhood in order to provide validating information for wind-borne debris modeling. Some typical damage photos are shown in Figure 3-35.



Figure 3-34. Hurricane Charley Neighborhoods Surveyed by ARA.

Gable vs. Hip. Figure 3-36 shows the results for average % roof cover damaged based on gable *vs*. hip roof shape. The hip roof covers experienced 15% average roof cover damage and the gable roof covers experienced 20% roof cover damage. Hence, the gable roof covers experienced, on average, 33% more roof cover damage than hips. Although % of roof cover damaged does not exactly correlate with loss costs, one would expect the % differences in the physical damage to be generally similar to the differences in loss costs. This difference is consistent with the 2002 study and the new preliminary work in this report, which reflects improved data on roof pressure load coefficients from wind tunnel tests.

Pre- and Post-FBC Performance. The results for roof cover type and pre-FBC vs. post-FBC are illustrated in Figure 3-37. Shingle and tile roof covers lost almost the same percentage of roof cover in terms of both pre-FBC and post-FBC homes. There is a noticeable difference in percent damage in terms of pre- FBC and post-FBC homes. Post-FBC homes lost about ½ the amount of roof cover, on average, than pre-FBC homes. This result is significant, although it includes the confounding effect of roof cover age of the pre-FBC covers being compared to basically new (less than 3 years old) post-FBC roof covers. In the 2002 study, we had to make engineering assumptions on the effectiveness of new roof covers without having actual performance data and the estimated loss reduction was about 15-20%.



Figure 3-35. Damage Photos from Hurricane ARA Charley Single-Family Home Survey.

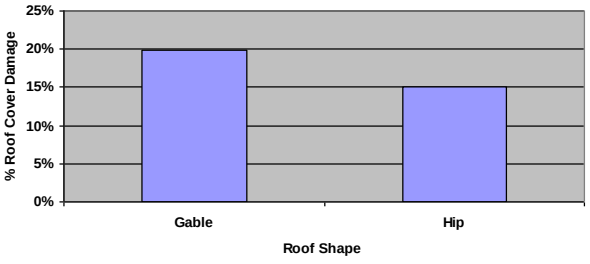


Figure 3-36. Average % Roof Cover Damage by Roof Shape (ARA Hurricane Charley Single-Family Home Survey).

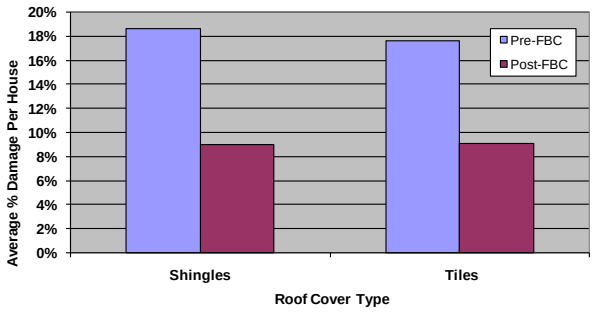


Figure 3-37. Pre- and Post-FBC Roof Cover Performance (ARA Hurricane Charley Single-Family Home Survey).

One major unknown is how well post-FBC roof covers will perform after 10 to 15 years of aging when compared to pre-FBC roof covers of the same age. Figure 3-38 shows a scatter plot of the Charley data for shingle roof covers and a linear regression fit to the data. The linear regression clearly shows the

affect of roof cover age.[19] These data support the introduction of an age-related factor for roof cover performance.

Figure 3-39 shows envelope performance in terms of pre- and post-FBC. Although only a few post-FBC houses were surveyed, the trends in this plot show the improved performance of post-FBC construction. This plot does not consider whether the house had opening protection or not.

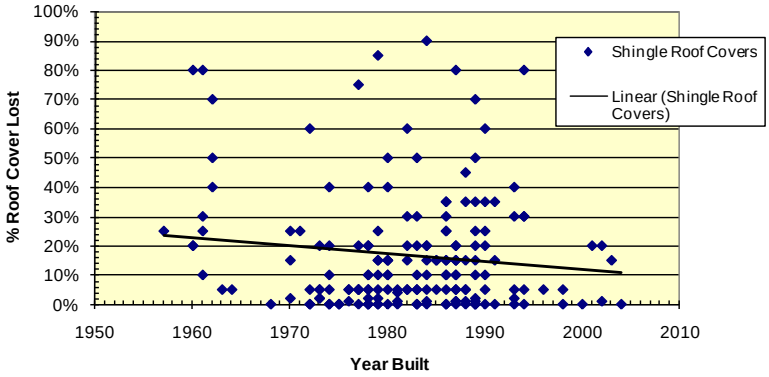


Figure 3-38. Shingle Roof Cover Damage vs. Year Built (ARA Hurricane Charley Single-Family Home Survey).

Tile Roof Cover Attachment. The effect of tile roof cover attachment is seen in Figure 3-40. Mortar embedded tiles perform about 50% worse than nail/screw attached tiles. Additional work is needed on tile attachment method for possible inclusion as a secondary factor.

Opening Protection. The effect of shutter protection of windows is illustrated in Figure 3-41. Only 6% of the homes with all windows protected experienced at least one damaged window, while about 28% of the homes with all windows unprotected experienced at least one damaged window.

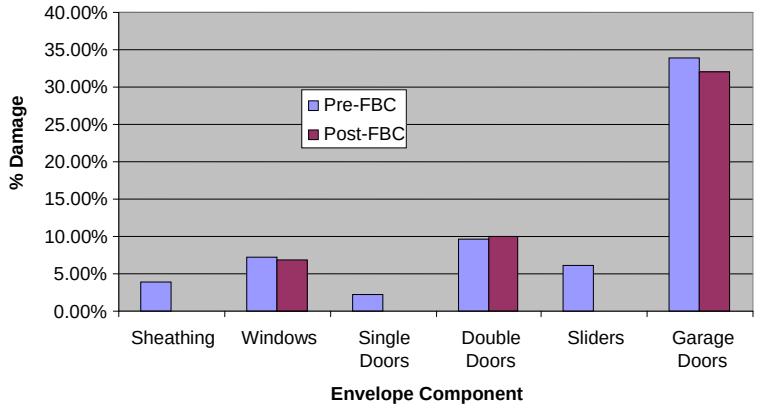


Figure 3-39. Pre- and Post-FBC Envelope Performance (ARA Hurricane Charley Single-Family Home Survey).

Attached Structures. The data collected in Hurricane Charley were suitable for an assessment of failures of attached aluminum frame screen enclosures. This analysis was for a total of 67 homes in several neighborhoods in the Punta Gorda area. The maximum peak gust windspeeds (at a height of 10 m in open terrain) were estimated to be about 140 mph. Figure 3-42 presents a plot of the modeled peak gust windspeeds at the locations of the homes used in the survey.

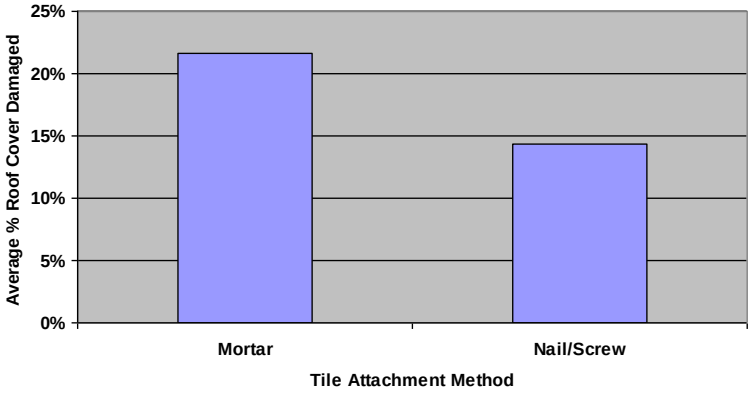


Figure 3-40. Tile Roof Cover Attachment Method (ARA Hurricane Charley Single-Family Home Survey).

[19] We note that the ARA survey did not focus on year built in the survey design, there were only a small sample of post-FBC homes in the data set. The UF and other surveys did include a good sample of post-FBC homes.

Fifty-two of the 67 homes had attached enclosures. Forty-seven of these experienced frame failures and 42 experience catastrophic-type collapse failure. Figure 3-43 summarizes the analysis and indicates that 79% of the aluminum screen enclosures experienced catastrophic failure (collapse). Eighty-nine percent experienced either partial frame failure or collapse failures. Seven percent experience screen failures with no frame failures, and 4% suffered no damage. Figure 3-44 shows the types of damage observed in the survey.

More details on this survey of attached structures and more discussion on attached and detached structures is given in Twisdale, et al. (2007). Attached aluminum frame structures are constructed to reduced loads, as allowed by the FBC, and have not had sufficient redundancy in the design to sustain damage without collapse. Wind mitigation rate differentials should not apply to that portion of the wind premium associated with attached or detached structures.

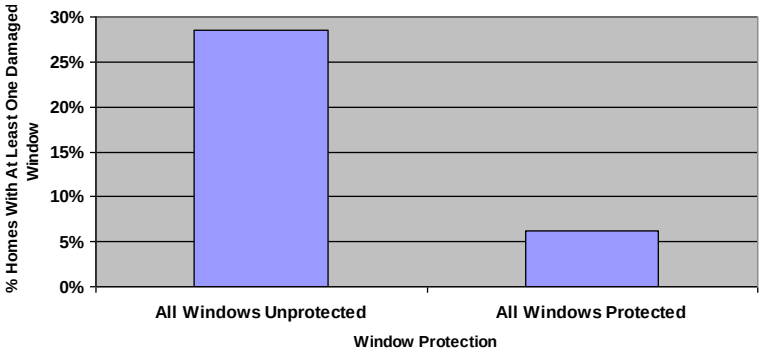


Figure 3-41. Effects of Opening Protection on Window Damage (ARA Hurricane Charley Single-Family Home Survey).

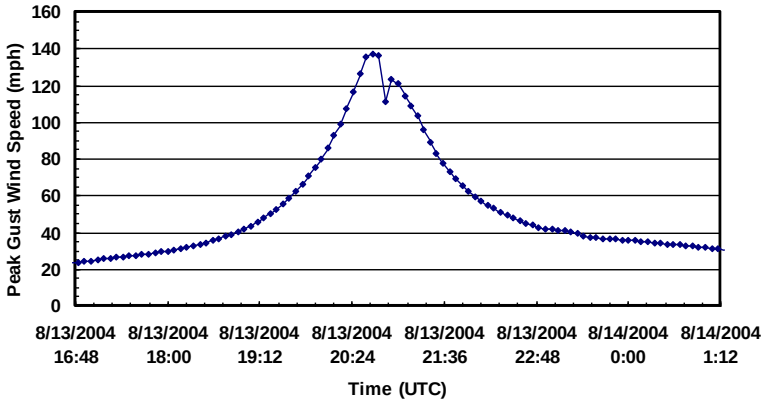


Figure 3-42. Modeled Peak Gust Windspeeds for Hurricane Charley at the Location of the Surveyed Screen Enclosures.

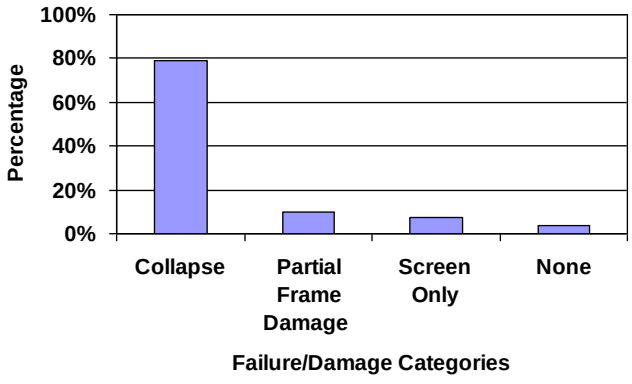


Figure 3-43. Performance of Screen Enclosures in Hurricane Charley.

3.6 Model Updates

With the substantial amounts of new information, in the form of insurance data, field damage surveys, and engineering research, some basic updating and improvement of the hurricane damage and loss models has been performed under this project. These updates do not represent a major model redevelopment effort, but do provide for improved loss estimation and validation against available data. Section 3.6.1 reviews some of the data and updates that have been performed for the loads and damage modeling. Section 3.6.2 summarizes key updates to the damage-to-loss model.



House 1.



House 2.



House 18.



House 21.



House 22.



House 31.



House 50.

Figure 3-44. Photos of Attached Structures in Punta Gorda Area.

3.6.1 Load and Damage Modeling

The major areas of new research include terrain effects, roof slope, water intrusion, soffits, rooftop equipment, and parapets.

3.6.1.1 Terrains and Velocity Profiles

Four different terrains will be used in the development of the loss relativities. Three of the four terrains correspond to the three terrains (B, C and D) as given in the Florida Building code and ASCE 7. The fourth terrain is representative of treed areas in Florida. The velocity profiles (variation of mean windspeeds and turbulence, or gustiness, with height) used to define the treed terrain were obtained from wind tunnel tests. The velocity profiles associated with the three code based terrains are described using the models for atmospheric turbulence as described in ESDU (1982, 1983). The surface roughness values, z_o, associated with Exposures D, C and B are 0.003 m, 0.03 m and 0.35 m, respectively. Note that the z_o values given for Exposures B, C and D, are representative values and do not necessarily match those specified in ASCE 7. Figure 3-45 presents the variation of the mean and gust windspeeds with height associated with the three code terrains and the treed terrain. The windspeeds are presented such that all profiles yield the same windspeed at a height of 250 ft above the ground. The differences in windspeeds

below this height are due to the effects of the local surface roughness. The figure shows how the windspeeds near the surface, where most buildings are located, decreases with increasing roughness. A comparison of the effect of the surface roughness on the mean windspeeds (left plot) and gust windspeeds (right plot), shows that the reduction in the mean windspeed associated with increasing z_o is greater than the associated reduction in the gust windspeed.

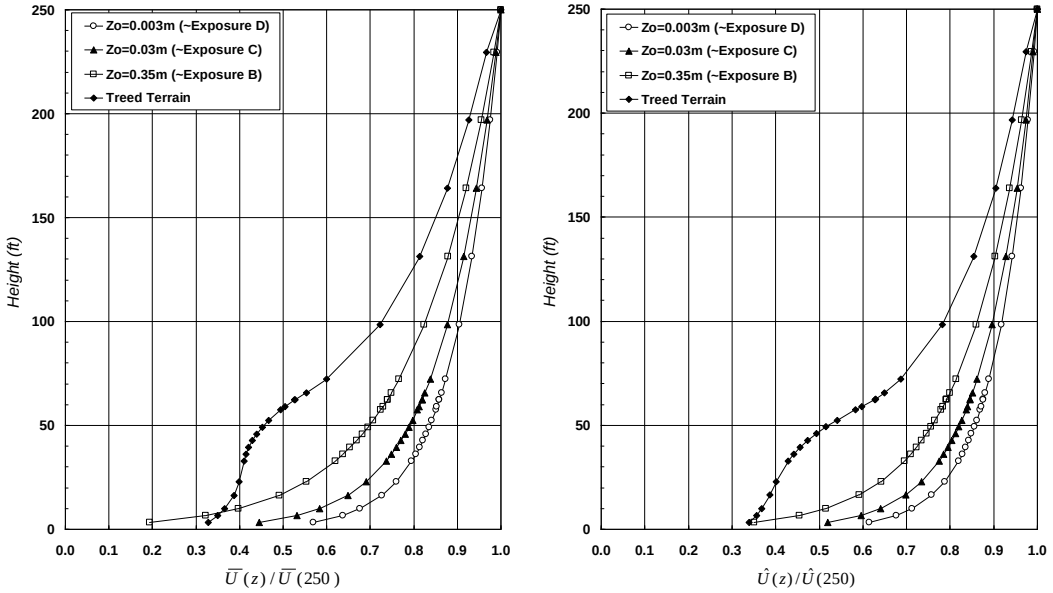


Figure 3-45. Comparison of Mean and Peak Gust Velocity Profiles.

3.6.1.2 Roof Slope Pressure Coefficients

A significant update to the pressure load model is the addition of new wind tunnel data for loads on roofs with a range of roof slopes. These new data have allowed us to start to address the potential impact on roof slope on loss costs. Figure 3-46 and Figure 3-47 present contour plots of pressure coefficients acting on the exterior roof surfaces of hip and gable roof buildings as obtained from wind tunnel tests. Contour plots are given for roof slopes of 4:12, 7:12, 9:12 and 12:12, with all four roof slopes represented by contours over ¼ of the roof surface in each plan view of the building. Contours are given for one-, two- and three-story building as well as for the buildings positioned in open and suburban terrains. All coefficients are defined as the peak pressure divided by the dynamic gust pressure at mean roof height. Thus in the case of one and two-story buildings, if the pressure coefficients on the two-story building are the same as those on a one-story building, the actual wind loads on the two-story building would be higher simply because the windspeeds at the mean roof height are higher in the case of a two-story building than a one-story building. In the case of the 4:12 roof slope, the height effect is made worse because the pressure coefficients near the roof eave actually increase as the building gets taller. This effect is not seen in the case of the higher roof slopes as the flow separation characteristics for these higher roof slope geometries is different than for the low slope roofs. Note that the height effect is more pronounced on the gable roof buildings than the hip roof buildings.

The effect of changes in roof slope on the pressures acting on the roof differs with both roof type (hip vs. gable) and location on the roof. For example, changing the roof slope from 4:12 to 7:12 and then to 9:12 reduces the uplift loads near the gable ridge and gable end areas but has little effect on the pressures near the gable eave.

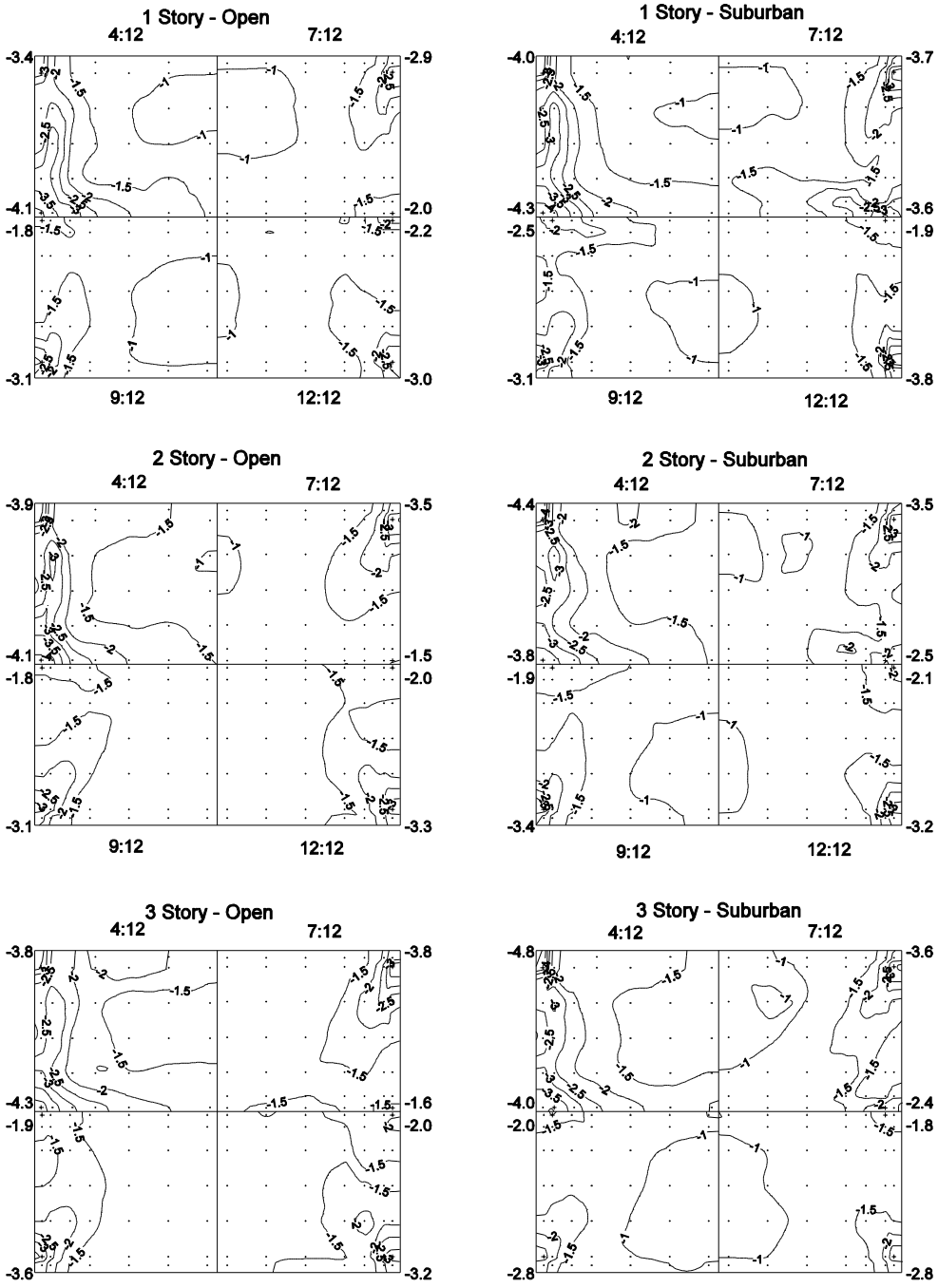


Figure 3-46. Pressure Contours on Gable Roofs as a Function of Building Height, Roof Slope and Terrain Type.

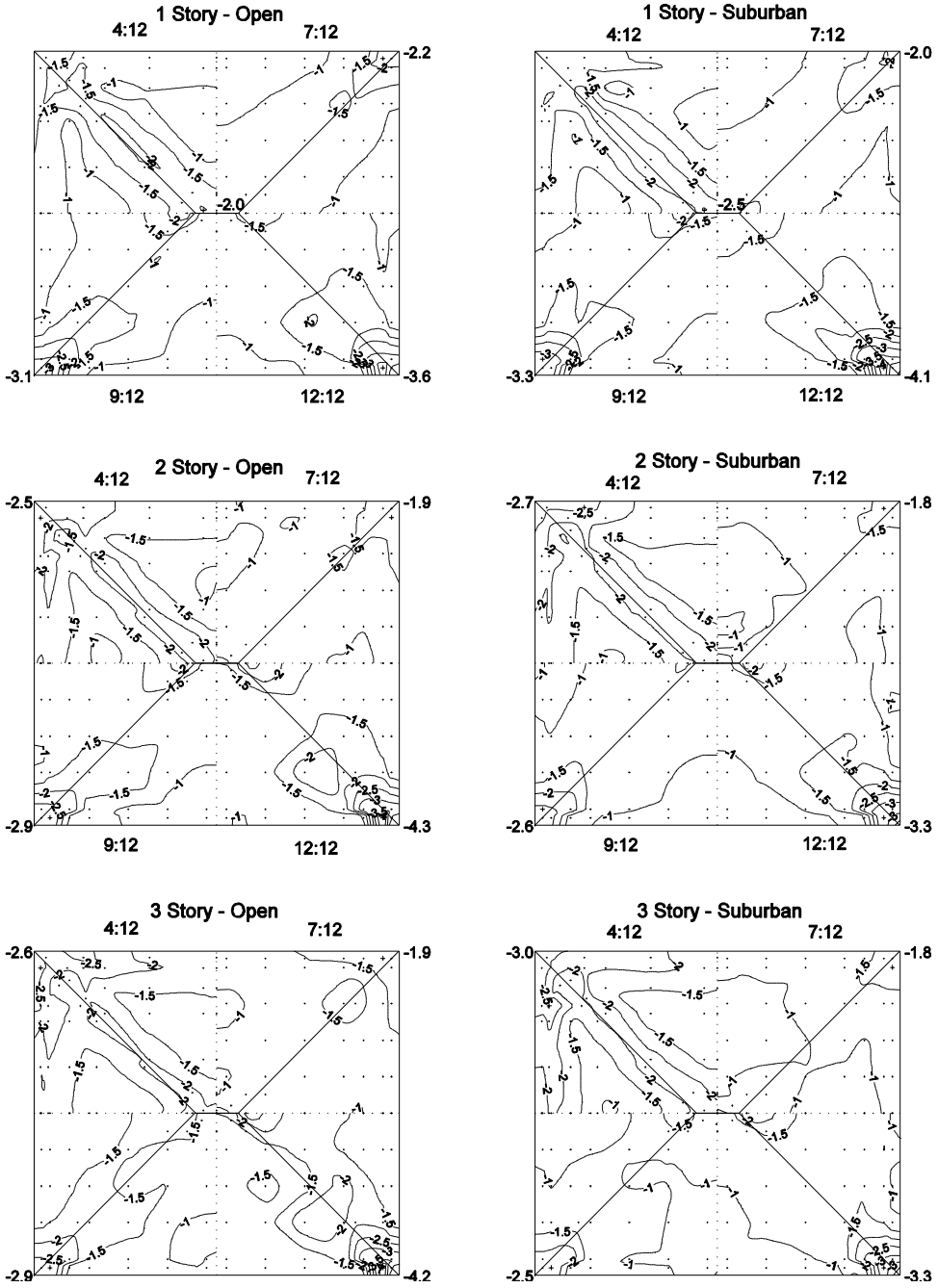


Figure 3-47. Pressure Contours on Hip Roofs as a Function of Building Height, Roof Slope and Terrain Type.

In the case of the hip roof, the uplift pressures near the eave corners are worst for the 12:12 roof slope. Qualitatively, it appears that the lowest uplift pressures are on the 7:12 roof, but it should be noted that the pressures are normalized by the dynamic gust pressure at mean roof height which increases with increasing roof slope, and thus a reduction in the wind load coefficient can be offset by an increase in the normalizing gust windspeed.

Two different approaches are used in the modeling of wind loads on the roofs of structures. The first method, which applies to sloped roofs, uses a zone approach, where each location of a roof is assigned to a zone based on its proximity to an edge. Both the magnitude of the pressure coefficients and their variation with wind direction is the same for any point within a zone, and are based on the results from wind tunnel tests. Figure 3-48 presents comparisons of the wind tunnel and empirical pressure load model pressure coefficients for the 4:12 slope and 7:12 slope hip roof cases. The upper figures compare the minimum (maximum uplift) pressure coefficients over 36 different wind directions and the lower plots presents the coefficients for each of 36 different wind directions.

The second method applies to buildings with flat roofs, where analytic functions are used to describe the variation of the pressure coefficients as a function of wind direction and location on the roof. Unlike the sloped roof model, the pressure coefficients vary within a zone.

Figure 3-49 presents a comparison of the empirical model and wind tunnel measured pressures acting the roof of one, two and three story flat roof buildings without parapets. Figure 3-50 presents a scatter plot showing the minimum (maximum uplift or suction) pressures on a flat roof derived from wind tunnel tests and from the empirical model. In both Figure 3-49 and Figure 3-50, the pressure coefficients are presented for one, two and three story buildings.

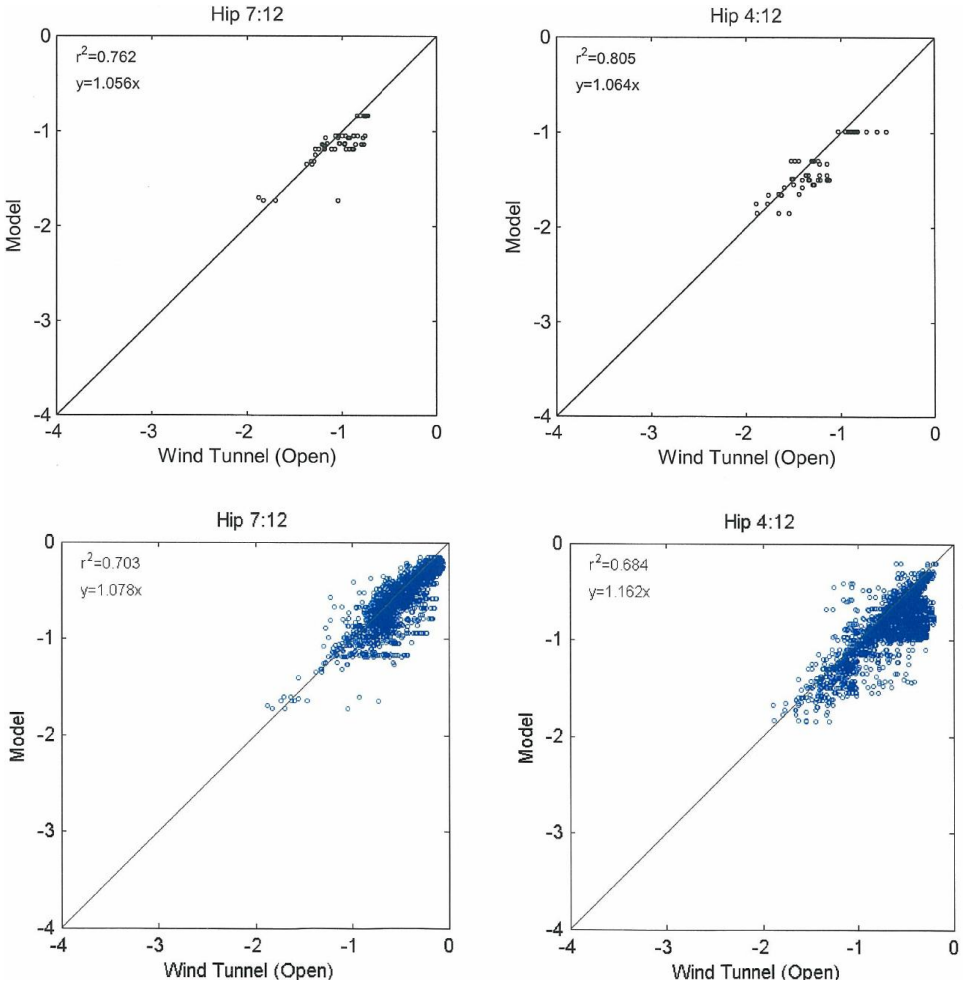


Figure 3-48. Comparisons of Wind Tunnel and Empirical Pressure Model Pressure Coefficients on the Roof of 4:12 and 7:12 Single Story Residential Buildings.

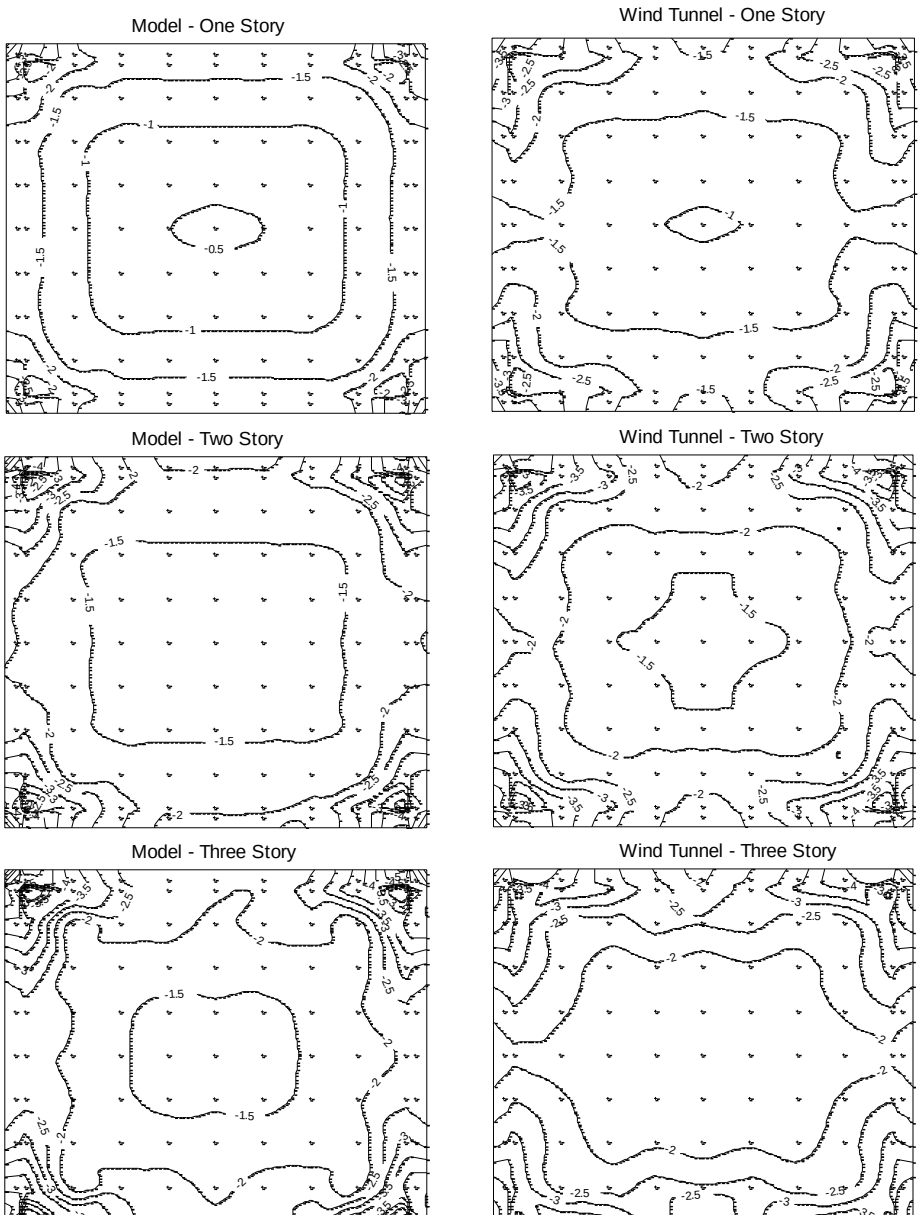


Figure 3-49. Comparison of Contours of Empirical Model and Wind Tunnel Pressure Coefficients Acting on the Roof Surface of a Building with a Flat Roof for a Building Positioned in Open Terrain.

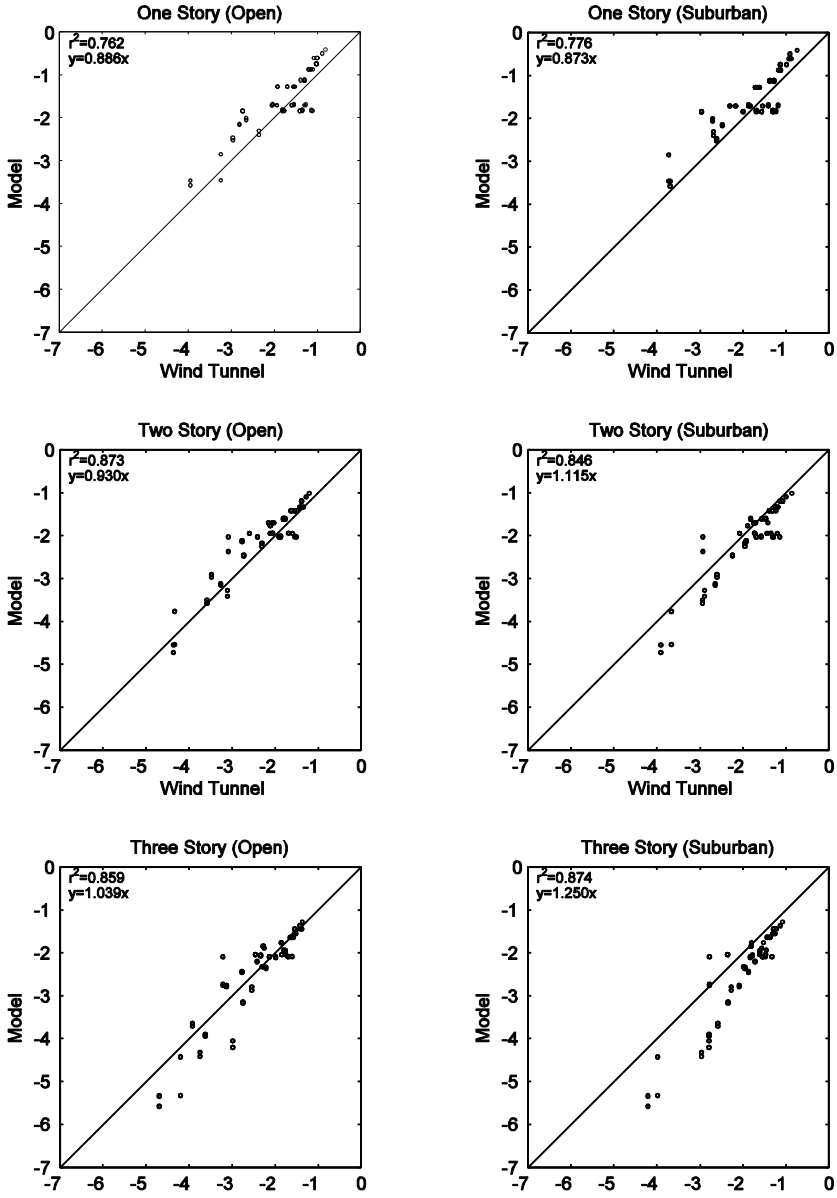


Figure 3-50. Comparison of Minimum Empirical Model and Wind Tunnel Pressure Coefficients Acting on the Roof Surface of a Building with a Flat Roof for a Building Positioned in Open Terrain. Pressure Coefficients Represent the Minimum Values over 36 Directions.

3.6.1.3 Water Leakage

Estimates of the quantity of water entering the building have been derived assuming that that the volume of air per unit time, *Q*, entering the building can be described by

$$Q = A \cdot C_w \cdot (\Delta p)^n \qquad \textit{(3-2)}$$

where *A* is the surface area of the window or door and *n* is a coefficient to be determined from full scale experiments of air leakage into buildings. C_w is a flow coefficient also obtained from experiments and varies with window type and installation. The flow coefficient, C_w, contains two terms which are added

together. The first portion of C_w is associated with leakage through the window system itself, the second is associated with water leakage around the perimeter of the window (or door). Δp is the pressure difference across the window (i.e., the difference between the pressure on the exterior of the building and the interior of the building). The amount of water that enters the building through the leaky windows is computed by assuming that all the rain water that is in the air also enters so that the volume of water that enters the building through leaky fenestrations is equal to Q times the ratio of water to air per unit volume. The water leakage computation is performed only when the pressure on the exterior of the window or door is positive. The portion of the coefficient C_w that is associated with window type approaches zero for fixed windows and windows that tend to "tighten" when subject to positive pressures, such as a casement window.

Additional work on water leakage should be initiated in coordination with the University of Florida experimental research program.

3.6.1.4 Soffits

Wind tunnel experiments examining wind induced pressures on soffits (Vickery, 2008) clearly indicate that the soffit pressures are equal to the wall pressures just beneath the soffits. The implementation of the load portion of the soffit model was performed by locating points on the walls of the model buildings just beneath the soffits and using the wall pressures computed at these points to act on the soffits. Both positive (upwards acting) and negative (downwards acting) pressures are computed.

The failure pressures for the soffits were derived from experimental data given in an unpublished draft report provide by the Institute for Business and Home Safety (IBHS). In this study, two classes of soffits are modeled: one where the soffits do not fail, and the other where the soffit resistance is based on the IBHS test data for vinyl soffits. If the soffits fail during the passage of a model hurricane, the exterior pressures acting at the location of the failed soffit section are transmitted to the interior of the structure and used in the computation of internal pressures for the failure of the entire roof and roof sheathing components. Similarly, we compute the amount of rain water entering the building associated with the volume of air flowing into the building though the failed soffit. As in the case of the "leaky" windows, the computation of the quantity of water entering the building is performed only when the pressures acting on the exterior of the failed soffit is positive.

3.6.1.5 Rooftop Equipment

A first principles-based rooftop equipment failure model has been developed. The model has been validated using result from wind tunnel tests. The wind tunnel test data include measurements of the windspeed at roof height required to topple a model cube positioned on the roof of a building. Figure 3-51 presents an example of the modeled and observed (wind tunnel) failure windspeeds for unrestrained rooftop equipment. For restrained equipment, we model the ultimate capacity of the straps using a load and resistance factor design approach.

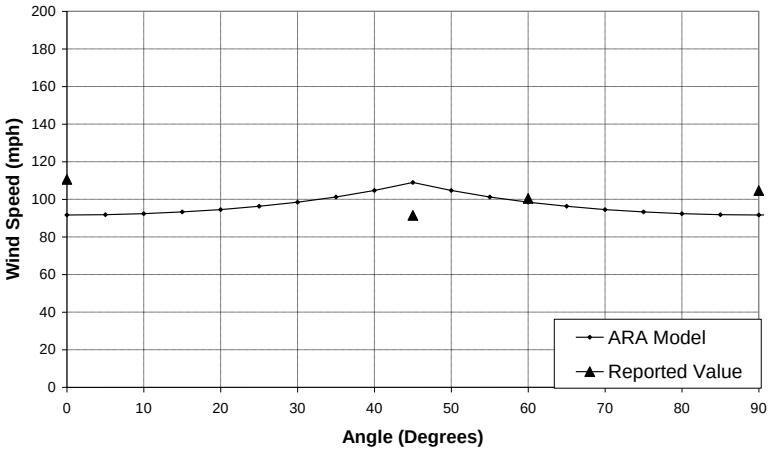


Figure 3-51. Comparison of Modeled and Observed (Wind Tunnel) Windspeeds Causing Overturning of Rooftop Equipment.

3.6.1.6 Parapets

The effect of parapets has been modeled by adjusting the model pressures on the roof to take into account the changes in the pressures brought about by the parapets. We have used the wind tunnel studies reported in Kopp et al (2005) to develop the adjustment factors for the roof uplift pressures. The results given in Kopp et al (2005) indicate that the effect of parapets on the roof pressures is a function of $h/(H+h)$where h is the parapet height and H is the mean roof height. Results are only given for five values of $h/(H+h)$, but only one value of H was used in the experiments (H=15'-9"). Significant reductions in roof uplift pressures at the corners were evident for $h/(H+h)\geq 0.29$, corresponding to h=5.9'. The uplift pressures reduced a little more as $h/(H+h)$ increases to 0.38. These were the only two cases where the existence of parapets reduced the edge uplift pressures to be less than those given in ASCE 7. Corner uplift pressures are less than ½ those given in ASCE 7 for $h/(H+h)\geq 0.29$.

Three roof uplift pressure reduction models were developed using the wind tunnel data given for $h/(H+h) = 0.29$ for application to locations in corners, edges and the interior zone. The pressure reduction model was developed as a function of parapet height rather than $h/(H+h)$. In the computation of loss relativities given herein, a parapet height of 6' is used. The parapet must be continuous along the full perimeter of the roof.

3.6.2 Damage-to-Loss Modeling

The damage-to-loss model takes the physically damaged building (after each simulated hurricane event) and "adjusts" (computes) the losses. The "damage-to-loss model" was updated on three different levels. The first level was necessary to accommodate the damage model updates described in Section 3.6.1. Specifically, soffit damage, water leakage and rooftop equipment damage that is predicted by the damage model are translated into loss by the damage-to-loss model. The second level involves the modeling of losses that are not dependent on the performance of the building envelope, including loss to exterior accessories, tree removal from covered property, and tree debris removal. The third level involves the manner in which the model translates roof cover damage-to-loss, which more accurately treats the claim adjusting process.

3.6.2.1 Loss from Additions to Damage Model

The ARA damage-to-loss model was updated to utilize new output produced by the updated hurricane damage model described in Section 3.6.1. The new output from the damage model includes the area of soffits damaged by the wind, additional water entering the building through in place windows and doors, and damage to rooftop equipment. The following sections describe how these new damage outputs are used by the damage-to-loss model to estimate loss.

Soffit Losses. The damage-to-loss model used for the 2002 loss relativities study included soffit loss as an additive term to the roofing loss because the soffit was not damaged separately by the damage model. The addition of direct wind damage to soffits in the damage model, the damage-to-loss model was updated to accommodate the new damage model. This change was accomplished by removing the additive term for soffit loss in the modeling of roof covering loss and adding a new function to predict soffit loss directly from the damage model output and replacement costs based on RS Means Residential Cost Data 2008 (RS Means 2008a). Replacement costs are compiled by soffit material types including aluminum, vinyl, wood, stucco, frieze block and frieze vent.

Water Leakage Loss. Water entering through in-place fenestrations (see Section 3.6.1.3) and through failed soffits (see Section 3.6.1.4) is output by the damage model as a part of the existing "fenestration water" term. This total amount of fenestration water is being used in an existing empirical relationship in the damage-to-loss model that predicts interior damage based on a quantity of water. There was no change needed to accommodate the change in the damage model, however, the net effect of the

change is that the loss model now predicts interior damage from fenestration water even if no fenestrations fail.

Rooftop Equipment Loss. Damage to rooftop equipment is estimated by the damage model and is reported as a separate item in the damage output file as either failed or not failed. The damage to rooftop equipment is reported for each building compartment and is based on a representative air conditioning unit on the roof that is sized based on the living area of the respective building compartment. Losses from damaged rooftop equipment are determined explicitly based on the size and replacement cost of the air conditioning unit required to cool the living area of its corresponding building compartment. Costs are based on RS Means Square Foot Costs 2008 (RS Means 2008b).

3.6.2.2 Losses Not Dependant on Building Envelope

The claim folder review helped identify and quantify sources of loss that are not necessarily related to damage to the building envelope. The sources identified include loss to exterior accessories, loss from tree removal and tree debris removal, and the effect of loss to attached and detached structures on the losses to the main building.

Data developed as a part of the claim folder review are used to quantify the magnitude of the losses to each of these areas for use in the damage-to-loss model. Given the limited number of claims reviewed, the claim folder review data is not appropriate to use for quantifying the frequency of these types of losses by wind speed. Claim frequency is better estimated using the policy level loss data The following subsections describe the probability of loss function developed in conjunction with the policy level loss data analyzed and the implementation of this function with the loss magnitudes developed in the claim folder review.

Probability-of-Loss Function. A new probability-of-loss function has been developed and implemented for use in conjunction with potential losses that were identified and quantified in the claim folder review. The probability-of-loss function estimates the frequency of losses for exterior accessories, tree removal, and tree debris removal. Figure 3-52 shows the probability-of-loss function plotted along with the claim frequencies developed in the policy level loss data analysis for insurers A and F. Note that the general shape of the probability-of-loss function follows the shapes of the policy level insurance data. The offset of the probability-of-loss function from the insurance claim frequency curves is intentional to account for the fact that the curves developed directly from the insurance data include the effect of substantial hurricane deductibles (typically 2%), which will reduce the claim frequency, especially at the low end.

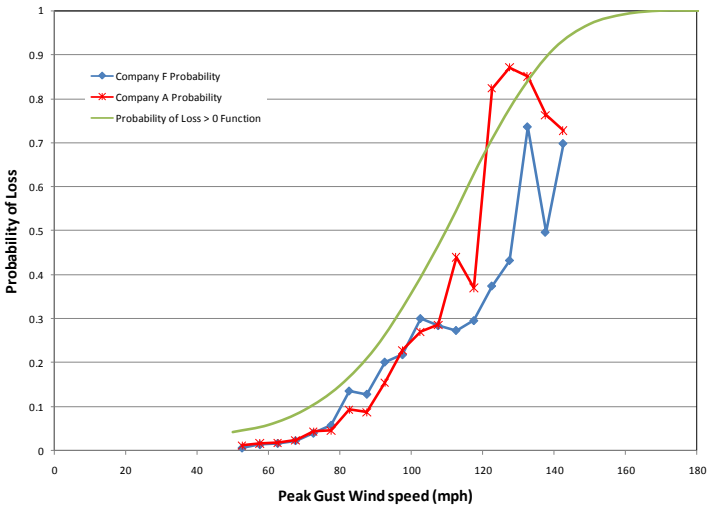


Figure 3-52. Probability-of-Loss Function.

Exterior Accessory Loss. The modeling of losses to exterior accessories uses the probability-of-loss function to determine whether or not an individual building will have a loss to exterior accessories. If an exterior accessory loss is modeled, then the magnitude of that loss is modeled based on the losses observed in the claim folder review.

Figure 3-53 shows that the exterior accessory loss data from the claim folder review tend to increase with wind speed. Beta distributions were fit to these data for several windspeed ranges in order to develop a model of the beta distribution parameters (α and β) by windspeed. The total value of an exterior accessory claim is then sampled from the modeled beta distribution given the peak gust wind speed at the site. The model of the beta distribution parameters was extrapolated for wind speeds greater than those observed in the claim folder review (maximum observed wind speed ~ 130 mph). Figure 3-54 compares the average exterior accessory losses from the claim folders with results from the model developed from the data. The losses in Figure 3-54 are shown as a proportion of the Coverage A value.

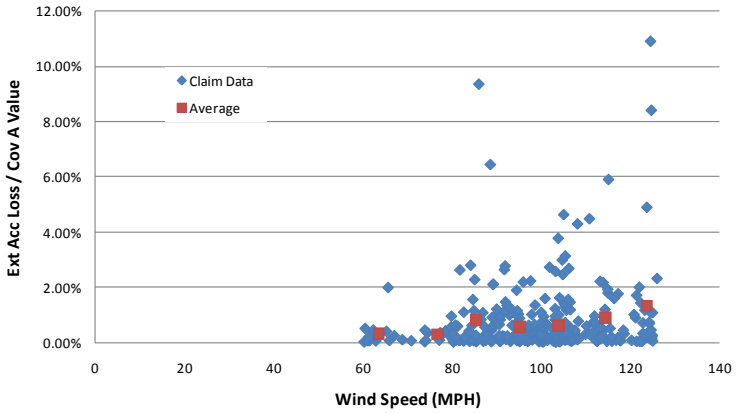


Figure 3-53. Exterior Accessory Losses vs. Windspeed.

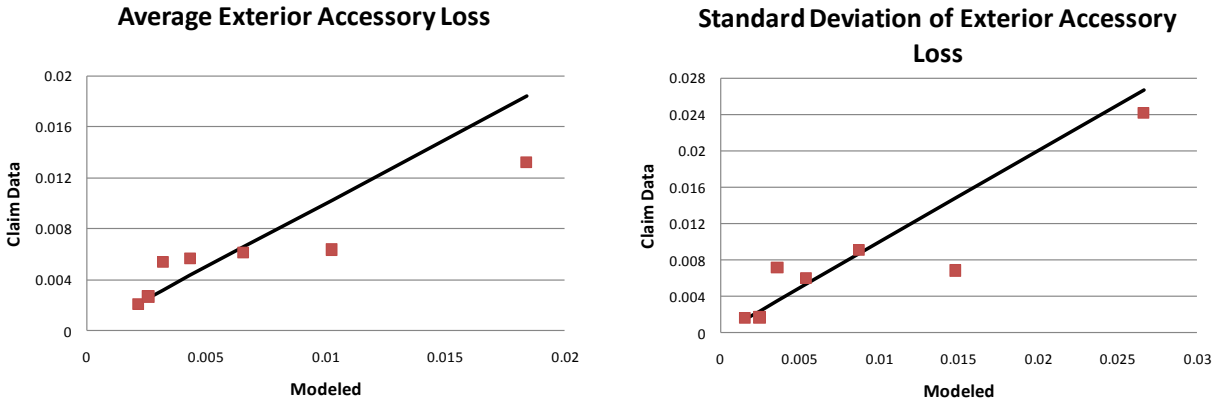


Figure 3-54. Claim Folder Data for Exterior Structure Loss vs. Modeled Loss.

Tree Removal and Tree Debris Removal Loss. The modeling of losses from tree removal and tree debris removal uses the probability-of-loss function to determine whether or not an individual building will have a loss due to tree removal and tree debris removal. If a tree removal loss is modeled, then the magnitude of that loss is determined based on the losses modeled from the claim folder review.

Figure 3- 3-55 shows the claim folder loss data for tree removal and tree debris removal by wind speed. This plot also includes an essentially flat trend line fit to the average losses by wind speed bin. The total value associated with the tree removal and tree debris removal claims has been fit to a lognormal distribution for incorporation into the damage-to-loss model.

Figure 3-56 shows a comparison of the resulting modeled tree removal and tree debris losses versus the losses observed in the claim folder review. The losses shown are a proportion of the coverage A value.

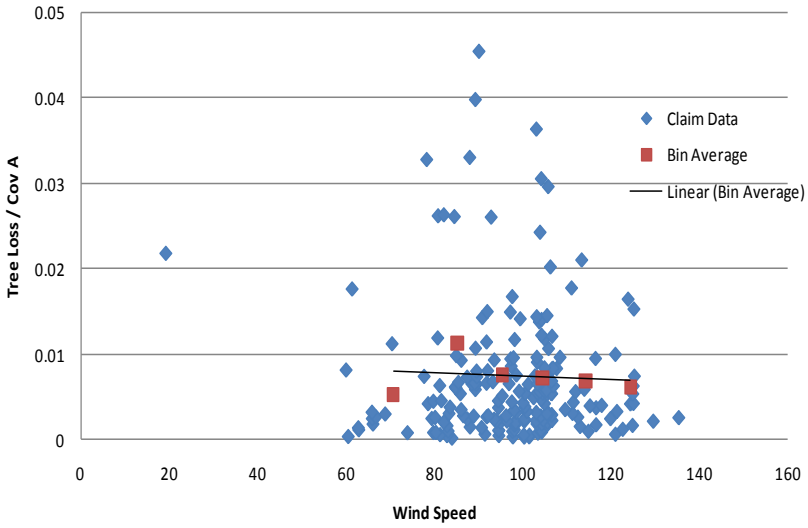


Figure 3- 3-55. Tree Removal and Tree Debris Removal Losses.

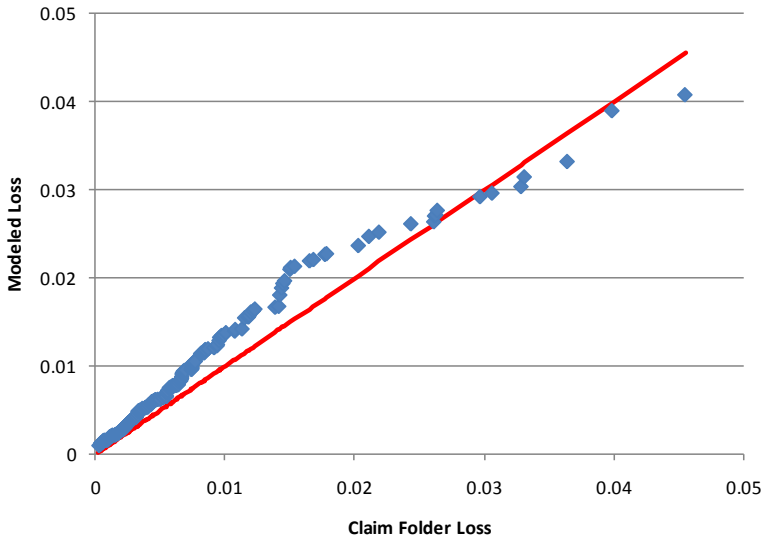


Figure 3-56. Modeled Tree Removal and tree debris removal losses vs. Losses Observed In Claim Folder Review.

Attached and Detached Structures. As previously discussed, losses from attached and detached structures have not been considered as a part of the losses that contribute to the loss relativities. However, data developed in the claim folder review showed that the claims from attached and detached structures can have an impact on the low end losses to buildings that actually get paid for by insurers as a result of payments made for attached and detached structures that reduce, or completely eliminate, the policy deductible. To illustrate this effect, example cases were run where the estimated loss from attached and detached structures were used to reduce the deductible before it gets applied to the building losses. This effect increases the likelihood of payments for low end losses experienced by buildings with 2% deductibles.

To perform these analyses, the damage-to-loss model was modified to call the probability-of-loss function described above and assuming values for all attached and detached structures based on the

results of an OIR study from 2007 (Twisdale, et al., 2007). Figure 3-57 shows the total value of attached and detached exterior structures by home as a fraction of Coverage A value and the resulting beta distribution used to model this value in the damage-to-loss model.

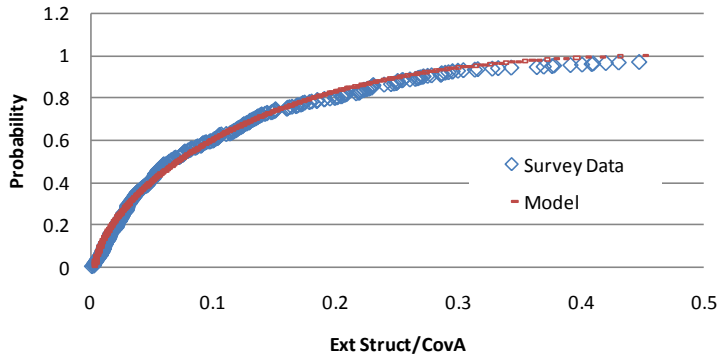


Figure 3-57. Probability Distribution of Total Attached and Detached Exterior Structure Values.

When this new function is activated, the resulting loss to these items is used to reduce the overall policy deductible and not included in the total loss value. This function was used for an example for an average, 1-story, gable roof home and resulted in an increase of about 14% in loss cost for the 2% deductible case.

3.6.2.3 Roof Cover Loss Calculation Changes

Detailed review of the roof covering related repair estimates as a part of the claim folder review led to two significant changes in the way that the damage-to-loss model estimated loss based on damage to roof covering. These two changes include the application of a minimum charge for roof covering repair and the implementation of a multiplier to account for the increased per unit costs associated with repairing a roof as opposed to replacing a roof. By their nature, both of these changes result in increasing low-level losses to buildings because they only affect those cases where there is a small amount of damage which will be repaired. If the entire roof is being replaced, then the application of a minimum charge will have no effect.

The damage-to-loss model used in the 2002 studies did not include a true minimum cost for roof covering repair, but did round up losses in $50 increments. The damage-to-loss model was updated to include the observed minimum values from the claim folder review.

The damage-to-loss model used in the 2002 studies used the same unit costs for roof covering repairs as roof covering replacements. However, the claim folder review undertaken for this study revealed that the unit cost for roofing repairs is generally several times the unit cost for roofing replacement due to the increased difficulty of repairing a roof without causing additional damage. As a result a repair cost modifier based on the relative unit cost for repairing versus replacing roof covering observed in the claim folder review was implemented.

4 Loss Relativities for Single-Family Residences

4.1 General

The key construction features for single-family houses that influence hurricane losses were introduced in Section 1.5. This section presents the analysis of key wind mitigation features that influence physical damage and loss for single-family houses in a hurricane. The analysis has been done for two main construction eras: pre-FBC and post-FBC. Pre-FBC construction refers to all site-built single-family buildings built to any code or standard other than the 2001 Florida Building Code (permitted prior to March 1, 2002). Post-FBC construction refers to any Florida home permitted on or after March 1, 2002.

The analysis by pre- and post-FBC follows the approach in the 2002 loss relativity studies. The determination of the presence/absence of wind mitigation features on houses built prior to the FBC is made from an inspection/verification process. That is, since homes permitted before March 1, 2002 were built to different standards in different parts of the state, it was concluded that the determination of wind mitigation features should be accomplished though visual inspection on a house-by-house basis. In other words, it was not practical to evaluate and develop county-specific loss relativities for all the possible year-built construction eras within various counties/regions on a statewide basis. Hence, the concept of verifiable wind mitigation features through an inspection process has driven the development of rate differentials for buildings permitted prior to March 1, 2002.

The introduction of the FBC in 2002 constituted a new era for Florida in the adoption of a uniform statewide building code. The new code included improved design requirements for wind loads and adopted a statewide wind-borne debris region. A significant amount of training of contractors, building officials, and design professionals has occurred in conjunction with the introduction of the FBC. The state continues to require building code education. Further, the Florida Building Commission's research program investigates areas for code improvements and assesses new code building performance in hurricanes. In recognition of these statewide requirements, the decision was made to develop loss relativities based on the minimal requirements of the FBC for post-FBC construction. That is, the loss relativities are determined by "looking-up" the relativity in a table for the wind zone and terrain in which the building was located. Hence, the loss relativity tables for post-FBC construction are simplified over the tables for pre-FBC construction since they use building code requirements instead of a visual inspection method.

The main concern in granting rate differentials based solely on building code requirements (instead of an "inspection"), centers on the quality of construction. For example, if the building code requires 8d nails at 6 inch spacing for the roof deck, and the contractor used 12 inch spacing, then the house was not constructed to the minimal requirements of the FBC. Although we do not have evidence to indicate that post-FBC quality is an issue, this assumption should be evaluated.[20] If quality of post-FBC construction becomes an issue in a county or region of the state, then it seems reasonable to require an inspection in those areas to determine the presence/absence of wind mitigation features. In that case, one should use the results of the inspection with the pre-FBC construction relativities to determine the rate differentials for which the building qualifies. Of course, an insurance company can always conduct its own inspection of a post-FBC property to ensure that certain verifiable features are in fact present and in good condition.

We note that insurance data analysis in Section 3.2 tends to support, in a general sense, the concept of eras based on pre- and post-FBC construction. The average losses for post-FBC construction were about 85% less than pre-FBC construction (see Table 3-3).

[20] A statewide statistically-based inspection program on post-FBC construction would enable quantification of the quality of new construction and validation of the use of rate differentials without an inspection-based system.

The main qualifications of the loss relativities developed in this section are:

1. ***Deductible.*** The relativities are based on 2% deductible. As discussed and illustrated in the 2002 report, the relativities are dependent on the deductible and the effect is nonlinear over the range from weak to strong buildings.
2. ***Dwelling.*** Rate differentials derived from the loss relativities are applicable only to the portion of the wind premium associated with the loss costs for the dwelling, its contents, and additional living expenses resulting from damage to the dwelling. The loss relativities should not be applied to any portion of the wind premium that is associated with the loss costs for attached or detached structures.[21]
3. ***Minimal Conditions.*** The building is assumed to be in reasonably good condition. In particular, the roof cover and windows/openings are not in a state of neglect and disrepair. Wooden roof decks are assumed to be at least Deck Type A. Our suggestion is that houses or buildings that are in a state of disrepair or do not meet minimal roof deck strength should not qualify for mitigation rate differentials until such components meet minimal condition requirements.

This section is organized into two main sections, pre-FBC and post-FBC construction. Section 4.2 covers pre-FBC and Section 4.3 covers post-FBC. Implementation of the loss relativities, in terms of insurance rate differentials and/or credits is presented in Section 6. Definitions and discussion of verification/inspection issues with respect to each wind-resistive feature are presented in Appendix A.

4.2 Pre-FBC Construction

Houses permitted before March 1, 2002 fall into the pre-FBC construction category. Detailed inspections and/or owner-provided verification forms are generally required to determine what mitigation features are present on a pre-FBC house.

Analyses of insurance policy level and claim data from recent Florida hurricanes were presented in Section 3. This information provides new data that were not available when the 2002 studies were performed. Other relevant research and damage surveys were also discussed in Section 3. In addition, several other relevant studies on loss relativities were conducted after the publication of the 2002 study (ARA, 2002a) and these are reviewed in this section.

These information sources are the starting point for determining what mitigation features to consider in this study. New features as well as old features are analyzed in this section to develop updated tables of loss relativities. Features that have a smaller effect on loss reduction are included as secondary factors due to both computational requirements and the desire to keep the main relativity tables at a reasonable size.

4.2.1 Single Family Mitigation Features

We begin by reviewing the mitigation features considered in the 2002 loss relativity study and the more recent Home Structure Rating System (HSRS) study.

2002 Loss Relativity Study. Table 4-1 summarizes the wind-resistive features modeled in the 2002 study. The primary rating factors are given in the top half of the table. The variables in the shaded area are secondary rating factors. Each wind-resistive feature is analyzed for several distinct "categories," where each category corresponds to a characteristic method of construction. For example, in 2002, the

[21] As given in Table 2-14, we used 0% for appurtenant structures (generally referred to as Coverage B) in the modeled results. Equally important, we did not include any attached structures (such as pool and patio screen enclosures, which are often covered as part of Coverage A) in the modeling of the dwelling losses.

roof-to-wall connection feature was analyzed for four categories: (1) toe nail, (2) clip, (3) wrap, and (4) double-wrap connections. The 2002 study included 576 combinations of features (288 for each of two terrains) in the primary relativity tables.

Table 4-1. 2002 Loss Relativity Studies Single-Family Construction Classification Features

Basic Feature	*Levels*	*General Description*
Primary Rating Features		
1. Terrain	2	FBC Terrain B, FBC Terrain C
2. Roof Shape	2	Hip, Other
3. Roof Covering	2	FBC equivalent, non-FBC equivalent
4. Secondary Water Resistance	2	No, Yes
5. Roof-to-Wall Connection	4	Toe Nail, Clip, Wrap, Double Wrap
6. Roof Deck Material/Attachment	3	Plywood/OSB (3 nail size/spacing: A, B, C)
7. Openings: Protection Level	3	None, Basic, Hurricane (SFBC/SSTD 12/ASTM E 1996)
Total 576		
Secondary Rating Features		
1. Openings: Protection Coverage	2	All Openings Protected, Only Glazed Openings Protected
2. Gable End Bracing	2	No, Yes
3. Wall Construction	3	Frame, Masonry, Reinforced Masonry
4. Wall-to-Foundation Restraint	2	No, Yes
5. Roof Deck Enhancements	2	Dimensional Lumber, Reinforced Concrete

Insurance Company Studies. Following the publication of the 2002 study, additional loss relativity studies were performed that extended the 2002 results. These studies addressed:

1. Number of Stories (one- and two-story homes)
2. Roof Cover Type (tile and non-tile)
3. Ordinary Opening Protection (wind resistive shutter products produced prior to impact testing standards).

Combining the results of these additional insurance studies with the 2002 study increased the number of entries in the basic table for pre-FBC single-family homes to 1,536 for each terrain, or to 3,072 for both FBC B and C Terrains. The primary relativities in the insurance studies were also adjusted by the secondary factors, similar to the 2002 study.

Home Structure Rating System (HSRS). Pursuant to Section 39, Senate Bill 1980, now known as Chapter 2006-12, Section 39 of the Laws of Florida, the Office of Insurance Regulation, in consultation with a designated Advisory Board, was tasked with studying and developing a program that provides an objective rating system to allow homeowners to evaluate the relative ability of Florida properties to withstand the wind loads from a sustained severe tropical storm or hurricane. The HSRS report (Twisdale, Wadhera, Vickery, and Sciaudone, 2007) is available on the OIR website.

Due to the limited time frame for the development of the HSRS and the desire to base the rating system on quantifiable measures of wind loss mitigation, the HSRS rating scale was founded on previously developed wind mitigation loss relativities. The starting point for the HSRS was the 3,072 combinations of wind mitigation features described above.

There were several HSRS adjustments to the 2002 study. These included roof pressure coefficients, secondary water resistance, and the use of ground-up losses (0% deductible). In addition, an updated set of secondary factors was included. Many of the updates were based on engineering judgment and included inputs by the HSRS Technical Advisory Board.

The secondary factors used in the HSRS are summarized in Table 4-2. The first seven secondary factors are similar to those in the 2002 Loss Relativity Study. Factors 8-11 were new factors. Enhanced roof deck refers to "code-plus" wood roof decks constructed with 5/8 inch thick plywood. Soffits and vinyl siding were introduced with a judgment-based penalties of 1.02 each. Window, door, and skylight water leakage potential penalties were introduced by counting the total number of openings in the building. The pressure difference across these openings tends to force water into the cracks that exist between the moving and stationary parts of the window or door. Water moves from the outside of the building to inside the building or into wall cavity. These factors were based on judgment coupled with general field observations and consideration that these components are designed to resist leakage for only 15% of the design pressure.

Table 4-2. Secondary Factors for HSRS. (Twisdale, Wadhera, Vickery and Driscoll, 2007)

No.	*Secondary Factor Description*	*Loss Relativity Multiplier (K_i)*				*Comments*
		2002 Study		*HSRS*		
1	Dimensional Lumber Deck	0.96		0.95		1 point reduction
2	Masonry Walls	0.98		0.97		1 point reduction
3	Reinforced Masonry Walls	0.95		0.94		1 point reduction
4	Opening Coverage – All Openings	0.98		0.96		2 point reduction, considering garages and large openings
5	Unbraced Gable End	1.02		1.03		1 point increase
6	Foundation Restraint	Ter B 1.38	Ter C 1.54	Ter B 1.10	Ter C 1.20	Reduced to reflect unanchored foundations vs. house on "blocks"
7	Reinforced Concrete Roof Deck Integrate with Concrete or Reinforced Masonry Walls Opening Protection: None	Ter B 0.44	Ter C 0.32	See Twisdale, Wadhera, Vickery, and Driscoll (2007).		Factors 1, 2, 3, and 5 do not apply for reinforced concrete roof deck integrated with reinforced concrete or masonry walls
	Opening Protection: Basic	0.38	0.20			
	Opening Protection: Hurricane	0.36	0.18			
8	Enhanced Roof Deck	-		0.99		New
9	Soffits	-		1.02		New
10	Vinyl Siding	-		1.02		New
11	Window, Door, and Skylight Water Leak Potential[1]:	-				New
	Total Number of Openings a. All Window Types Except Casement and Fixed			No Shutter	Shutter	
	≤ 5	-		1.020	1.010	
	6 to 10	-		1.040	1.020	
	11 to 20	-		1.070	1.035	
	21 to 30	-		1.100	1.050	
	31 to 40	-		1.130	1.065	
	≥ 41	-		1.160	1.080	
	b. Casement and Fixed					
	≤ 5	-		1.012	1.007	
	6 to 10	-		1.024	1.014	
	11 to 20	-		1.042	1.025	
	21 to 30	-		1.060	1.036	
	31 to 40	-		1.078	1.047	
	≥ 41	-		1.096	1.058	

[1] Each sliding glass door is counted as 4 openings in determining the total number of openings. All other openings (doors, windows and skylights) are counted as one each.

The HSRS uses the inspection results of a home to compute its loss relativity. It considers building location according to its FBC wind zone location. The loss relativity is then converted to a score between 1 and 100. It is important to note that the HSRS rating was not intended to be used or interpreted as a simplified stand-alone insurance rating measure. The HSRS scale was developed using loss relativities combined with building code requirements in each wind zone, and also uses a nonlinear risk-averse scoring function to promote wind mitigation of homes.

4.2.2 Primary vs. Secondary Factors

The separation of primary and secondary factors in previous studies was an attempt to keep the size of the tables manageable. In addition, the sheer number of the required calculations, which double every time a new two-level feature is added, quickly reaches unacceptable levels. Secondary factors are those that are believed to have a reduced impact on losses or features that are known to be important. We recognize that secondary factors should not be applied independently of the primary factors because their effects are non-linear over the whole range of the primary table.[22] An improved approach to updating relativities with secondary factors is presented in Section 4.2.5.

In an effort to simplify the results of the 2002 single-family study, the OIR chose to neglect or combine the secondary factors in Informational Memorandum OIR-03-001M. The OIR felt that the differences were minimal in some cases and their simplification reduced the complexity of the resulting credits. However, we believe that secondary factors should not be dropped from consideration based on a short-term goal of simplification. The building code will continue to evolve and the measured effects of key primary and secondary factors will improve. Secondary factors may become primary factors and their relative importance may also change. Hence, the mitigation rating approach should be comprehensive and not omit relevant factors.

We also note that the cost of inspections is largely a cost of getting the inspector to the site, and the collection of a few more bits of information has little, if any, additional inspection cost associated with it. Further, each 1% loss reduction that is "wrung out" statewide for existing (through mitigation) and new construction (through building code improvements) reduces the average annual losses in the state by about $50 million dollars. Every loss mitigation improvement that is made to a building reduces the risk of loss (generally) for decades. Hence, insurance companies and the state needs to take a long term view regarding the goals and rewards of wind loss mitigation programs.

Opening protection is an important primary feature. There are many acceptable products and, hence, differences in performance among protection options require the use of secondary factors. Options for opening protection include the use of impact resistant glazing, impact resistant coverings, and also wood structural panels, per the FBC.[23] Impact testing of wood panel shutters was performed in 2003-4 and the results of those Florida Department of Community Affairs (DCA) funded tests are included in this study through the use of secondary factors.

4.2.3 Analysis by Location

The 2002 loss relativities for existing construction included a single table of relativities for use statewide. An analysis by location showed that the variation in relativities was typically less than 25% for most locations.

[22] The nonlinearity of effect is due to the way losses quickly accumulate for a failure of any part of the building envelope. Secondary factors often have a notable impact on relativities for strong buildings. That is, for a generally strong building with only one weakness, the effect of the secondary factor is generally many times that of the effect of the secondary factor on an average building. For a weak building the secondary factor may not be very important since the building has so many other problems.

[23] For non-HVHZ locations in Florida, wood structural panels can be used for protection of openings without meeting the impact and pressure cycling test requirements. See FBC Section 1606.1.4 for wood panel fastening requirements.

Table 4-3. Location Sensitivity Cases

Location Points and Windspeeds (6)	Terrains (2)	Variable House Features (8)	House Strengths (3)	Strength Features
1 (90 mph) 6 (110 mph) 8 (120 mph) 11 (100 mph) 13 (130 mph) 17 (136 mph)	Terrain B Terrain C	1, 2 stories (2) Tile, non-tile (2) SWR, no SWR (2)	"Weak"	non-FBC Rf. Deck A Toe Nails No Open Prot. Other soffits
			"Mid"	non-FBC Rf. Deck A Toe Nails No Open Prot. Other soffits
			"Strong"	non-FBC Rf. Deck A Toe Nails No Open Prot. Other soffits

We have analyzed three sets of mitigation features for 6 locations and 2 terrains to assess the magnitudes of differences in loss relativity by location. Table 4-3 summarizes the house features and locations used in the sensitivity study. The weak and strong houses were selected in order to bound the range of resulting relativities. The total number of simulation cases equals: 6 locations × 2 terrains × 8 variable features × 3 house strengths = 288 runs. A total of 24 houses were run for each location and terrain. The loss relativities were produced for each location by dividing the loss costs for each house by the loss costs of the weakest house.

Analysis Results. Figure 4-1 is a scatter plot of the relativities for Points 1, 6, 8, 11, and 17 vs. Point 13. If the relativities were perfectly correlated from site to site, there would be no scatter along the superimposed 45 degree line. The error introduced in using a single location (point 13 in this case) for the entire state can be seen by the scatter around the 45 degree line. The deviations are generally close (average site-to-site r^2 = 92% for Terrain B and 91% for Terrain C). However, there are some cases where the relativities are in error by as much as 60% in Terrain B and 75% in Terrain C.

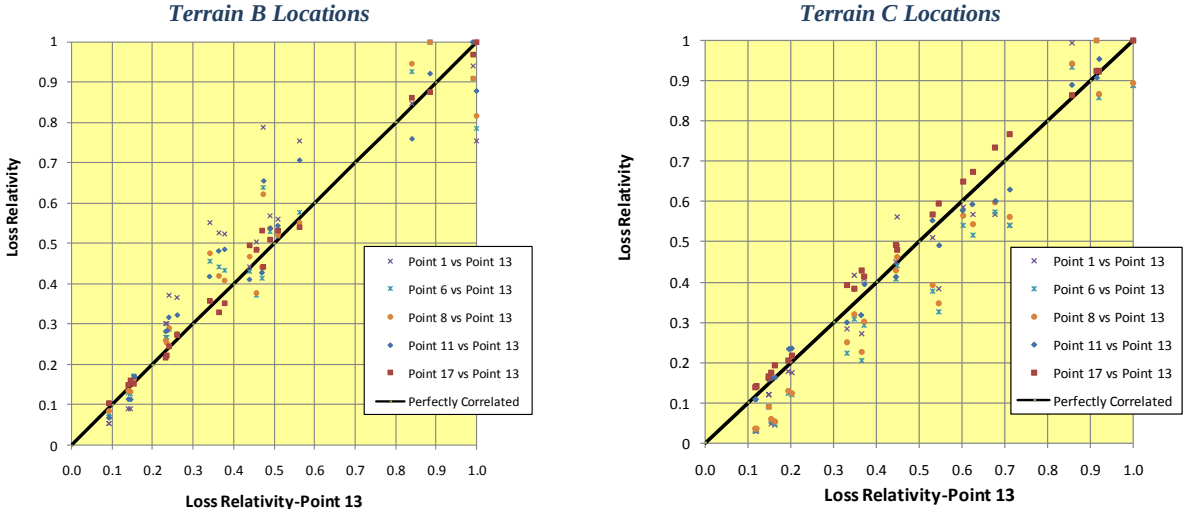


Figure 4-1. Pre-FBC Loss Relativity Location Correlation Plots

These errors can be translated into rate differentials, assuming the rate differentials are credits (C = 1 - R) from the weakest house. We compute the average credit error for these 24 houses at each location to be 1.9% for Terrain B (when averaged over all 6 locations, including location 13 as the base location for the state). That is, by using Location 13 relativities for statewide relativities, the average overpayment of credits is 1.9%, assuming the credit is based off of the weakest house. The maximum Terrain B credit error is 31% and the minimum credit error is -24%. Similarly for Terrain C, we found the average credit error to be -2.6%, the maximum credit error to be 14% and the minimum to be -22%. Thus, Terrain C

credit error results in a average underpayment of credit of 2.6%. These statistics are unweighted values that do not consider the statistical distribution of building stock strengths. Nevertheless, they give some indication that the average credit errors are tolerable if one uses a single table for statewide rate differentials, although the maximum and minimum errors are significant.

The maximum deviations in Figure 4-1 are for locations with lower wind hazards than Point 13. The fact that the loss costs are lower indicates that any error in rate differential will have a lower impact on the homeowner since the rates are lower.

An illustration of how loss relativities for lower wind hazard locations translate into rate differentials is given in Figure 4-2 for Terrains B and C. For each location, the loss relativity and loss cost relationship is linear. The slope of the line, which would pass through (0,0), if there were a zero loss-cost building, is the loss cost of the weakest building at that location. Thus, for lower hazard locations (very low slope lines in Figure 4-2), errors in loss relativities naturally have a much smaller impact in terms of errors in loss costs. Based on this analysis and given the limited schedule for this project, we must use a single location to produce a single statewide loss relativity table for pre-FBC construction.

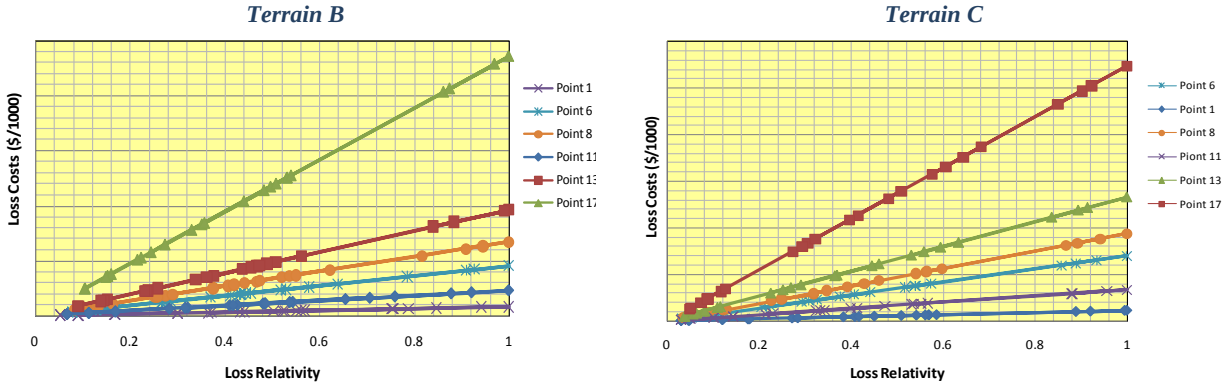


Figure 4-2. Pre-FBC Loss Costs vs. Loss Relativity

Discussion of Location-Dependent Relativities and Terrain. As a final point, we emphasize that we have only considered two terrains in this study, Terrain B and Terrain C. We have not considered a separate treed terrain, which occurs to various extents in central and northern Florida.[24] Nor have we considered a coastal terrain (typical of a barrier island or the first 600 feet of exposure next to the ocean or large sound or bay). Coastal terrains experience higher windspeeds than open terrains and have the additional hazards of sand and salt spray entrained in the wind, which further escalates the damage to buildings, equipment, and interiors, thereby adding to loss costs.

The loss relativities will be different in these additional terrains, particularly treed terrains. However, schedule constraints precluded these additional terrain considerations in this study. The limitation on terrains is mentioned here since it is also pertinent to the regionalization of loss relativities. The logic of location-dependent relativities and terrain go hand-in-hand since many of the lower hurricane hazard locations in Florida include treed terrain. As suggested by the windspeed profiles in Figure 2-5, treed terrains significantly reduce the windspeeds experienced by small buildings and hence significantly reduce the pressure loads on such buildings. Hence, one would expect to see smaller differences in the relativities (resulting in reduced rate differentials) in going from a weak to a strong building in a treed subdivision. Since most wind mitigation features provide for a stronger building envelope for wind

[24] Treed terrain does not mean an occasional tree, but rather sufficient tree density over local areas and within neighborhoods to produce the type of wind profiles seen in Figure 2-5. We expect that a notable percentage of neighborhoods in the northern half of Florida would be classified as treed terrain. Schedule did not permit us to develop loss relativities for treed terrain in this research, but we strongly recommend that treed terrain considerations be incorporated into loss relativities.

pressures, these features will be less important in a treed environment. Further, since current wind mitigation features are not explicitly designed to reduce the effects of damage from tree fall on a small building, the differences in loss between a (wind-pressure) mitigated and a (wind-pressure) unmitigated house in a treed environment are expected to be less.

These considerations combine to suggest that separate tables of loss relativities for the mid and northern parts of Florida, would need to consider a treed terrain. We recommend that these limitations be addressed in both the building code and in future updates to the wind loss mitigation relativities. We believe that location and terrain dependence could be handled sufficiently with about 3 to 4 Florida Regions and 4 terrains (B, C, D, Treed). This approach would result in much smaller deviations for rate differentials for mitigated homes.

4.2.4 Loss Relativity Tables

With consideration of previous work and the new hurricane damage and loss data analysis, we selected the 11 features in Table 4-4 for consideration for the primary mitigation rating variables for single family homes. The new primary features over the 2002 loss relativity study include:

1. Roof Cover (Tile and non-Tile)
2. Number of Stories (One and Two)
3. Soffits (Wood and Other)
4. Roof Slope (4/12 and 7/12)

Three of these items were treated in some fashion in the post-2002 studies and in the 2007 HSRS research described in Section 4.2.1. The insurance and damage data, wind tunnel testing, and field observations suggest that these features are important mitigation features

Table 4-4. Loss Relativity Analysis Matrix.

Basic Feature	*Levels*	*General Description*
Primary Rating Features		
1. Terrain	2	Terrain B, Terrain C
2. Roof Shape	2	Hip, Other
3. Roof Covering Type	2	Tile, Non –Tile
4. Roof Cover Strength	2	FBC, non-FBC
5. Secondary Water Protection	2	No, Yes
6. Roof-to-Wall Connection	3	Toe Nail, Clip, Wrap
7. Roof Deck Material/Attachment	3	Plywood/OSB (3 nail size/spacings)
8. Openings: Protection Level	2	None, ASTM E 1996
9. Roof Slope	2	4/12, 7/12
10. Soffits	2	Wood, Other
11. Number of Stories	2	One, Two or more
Total No. Combinations of PRF	4,608	

The total number of combinations in Table 4-4 is 4,608. Since the results are grouped and normalized by terrain, each terrain table has 2,304 entries. We note that Table 4-4 includes some simplifications from the 2002 relativities. First, we have reduced the number of levels of opening protection from 3 (none, ordinary, and hurricane) to 2 (none and hurricane). In studies for the Florida Department of Community Affairs for wood panel shutters in 2003-2004, we found that interpolation between none and hurricane for other shutter types was an accurate approach. Hence, an interpolation approach will be used herein for shutter type and treated as a secondary rating factor. Second, we eliminated the "double wrap" level for roof-to-wall connection. There was very little difference in the wrap and double wrap results for most parts of the state. We introduce double wrap as a secondary factor.

While the size of the pre-FBC single family tables for each terrain are 8 times larger (2,304/288) than the 2002 table, the new features introduce only a few new fields to an insurer's data for each property. Most insurers already have information on the number of stories and many have information on

roof cover type. Roof slope and soffit material would be the potentially new mitigation features. Hence, one should not confuse the size of the loss relativity table with the data storage requirements for each residence. For each residence, one only needs to know if the mitigation feature is present or not (or what level of mitigation is present for that feature), while the loss relativity tables take into account all possible combinations of features. The loss relativity tables or the wind mitigation credit tables are stored as a single separate table and are obviously not repeated for each policy. These tables are basically "look-up" tables in a database and their size is not a practical concern for modern computer systems.

4.2.4.1 Minimal Conditions

The loss relativities are based on the fundamental assumption that each wind mitigation feature is in good condition and able to perform its function. Obviously rotting wood or heavily corroded roof straps do not qualify for mitigation rate differentials and these conditions should be noted in the mitigation inspections.

Roof Cover Condition. An important condition assumption inherent in this updated study is roof cover condition. The modeled results assume that the roof cover is in good condition and can be repaired if some of the roof cover fails. For example, if a shingle roof in good condition losses <1% of its cover in a hurricane, this amount of loss generally results in repair and replacement of the damaged shingles and does not result in a total re-roof of the building. However, if the roof cover is in disrepair and cannot be repaired because the existing material is in very poor condition, then <1% loss in roof cover may require a total recovering of the building. The loss relativities were not derived for roof covers in poor condition (non-repairable by partial recovering). We do not believe that roof covers in poor condition should qualify for mitigation rate differentials. That is, if the building has a degraded roof cover, it should not qualify for mitigation rate differentials (regardless of what other mitigation features are on the building) until the roof cover is replaced. The rationale behind this recommendation is that the loss relativities are so dependent on the roof cover that an entire table of relativities would need to be developed for poorly-conditioned roof covers.

Window Condition. Another condition assumption in this study is that windows are in reasonably good condition. Windows that are in disrepair (or have large gaps) will allow large amounts of water (from the wind-driven rain within a hurricane) to enter the building without the window actually failing from pressure or missile loads. While shutters over these windows may act as a rain screen and thereby help reduce the amount of water leakage in a hurricane, the loss relativities were not developed for buildings with windows in a state of neglect with large visible cracks or gaps, or otherwise in obvious need of replacement. We do not believe buildings with windows that are in clear need of replacement/repair should qualify for wind mitigation rate differentials, regardless of the presence/absence of other features.

Roof Deck Minimal Strength. The weakest roof deck strength that we have analyzed is Roof Deck A, which corresponds to 6 penny nails at 6-12" spacing. If the mitigation inspection indicates that the roof deck is notably weaker that this attachment strength, we recommend that the house not qualify for any wind mitigation rate differentials. Such cases may occur when there are numerous nails that have missed the rafter or truss, or the deck has been stapled with fasteners that don't have sufficient penetration. The definitions and conditions for not meeting the minimal roof deck strength are discussed in Appendix A. Since the roof experiences the highest loads on the building, minimal roof deck strength is fundamental to building performance. Failure of a weak section of roof deck in low winds can lead to significant losses due to water entry into the building. Further, a very weak roof deck tends to negate the benefits of good roof cover condition as a result of potential premature failure of the deck prior to loss of roof cover.

4.2.4.2 Consideration of Window/Door Type

In developing the loss relativity tables, we began with a larger number of features than shown in Table 4-4. Our approach was to analyze a practical set of potential key factors and then, later, to reduce and simplify to whatever degree is necessary. Less important factors could become secondary factors or eliminated from consideration.

Windows/doors are currently designed to resist water leakage only to 15% of the design pressure. All windows and doors are expected to leak under high pressures. The amount of water that enters a building through leaky windows depends on the gaps along the perimeter of the window system. The gap flow coefficient is less for fixed windows and windows that tend to tighten when subject to positive pressure, such as casement windows.

We initially included window/door types as a measure of potential water leakiness (see Feature 11 in Table 4-2) as a primary feature in the simulations. We treated casement windows and fixed (picture) windows in one group and all other window types in the "other" group. Inclusion of window/door leak potential produced 9,216 combinations that were analyzed initially. Based on the results of these analyses, we concluded that window/door type should be treated as a secondary factor for single family homes.[25]

4.2.4.3 Loss Relativities Normalized by Typical Construction

The loss relativities are defined as the loss cost for a given house (computed using a 2% deductible and excluding exterior attached or detached structures) divided by the loss cost associated with an arbitrarily selected house within the matrix. The best way to assess the reasonableness of loss relativities is to measure differences from a typically-constructed building. This is analogous to the fact that insurance base rates in a territory are derived from averages of loss over many building types and wind mitigation features. We select the "typical" house or the "normalizing" house as one that has the same features as the normalizing house in the 2002 study (one story, gable, shingle, no SWR, non-FBC, Roof Deck B, Clip, no shutters). This house is assumed to be a "typical" level of construction in Florida. It is certainly not the strongest and nor is it close to the weakest.

Table 4-5 and Table 4-6 present the primary loss relativity results for one- and two-story single family homes located in Terrain B. Table 4-7 and Table 4-8 present the results for Terrain C. The relativities presented in the tables include the new models for roof loads including roof slope, new soffit loads and failure models, the addition of tile roofs and the inclusion of two-story houses. The modeling of soffit failures allows for the intrusion of water and for internal pressurization of the attic space.

Range of Relativities. We see that the strongest houses have a relativity of about 0.4 in Terrain B and 0.3 in Terrain C. That is, the strongest houses would have losses that average 2.5 to 3.5 times less than the typical house. We note that these relativities are very similar to those developed in 2002, in which the strongest Terrain B house had a relativity of 0.41 [Table 3-2 in ARA (2002a)] and the strongest Terrain C house had a relativity of 0.21 [Table 3-3 in ARA (2002a)]. The reason that these values did not change appreciably is due, in part, to the fact that the 2002 relativities were developed only for 1 story buildings with shingle roof covers. The 2008 relativities include 2 story buildings and tile roof covers. Two story buildings and tile roofs have higher losses, so the stronger houses in both the 2002 and 2008 studies have similar relativities. However, the strongest house in 2008 is not exactly the same house as in 2002, since we have introduced roof slope in 2008. The 2002 houses were analyzed with a single slope (4:12).

[25] Additional research is needed to further refine and validate water intrusion through openings and wall systems. Research is underway at the University of Florida in this area. Future damage surveys will also focus on this to help validate and improve predictions of effects on loss costs and classification of openings for potential leakiness.

Table 4-5. Terrain B Loss Relativities: (Non-FBC Roof Cover) Normalized to Typical House

Terrain B Single Family					Low Roof Slope (<= 5.12)																Other Roof Slope (>=6:12)											
					Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile				Two Story non-Tile				One Story non-Tile				Two Story Tile			
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip	
					No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
Non-FBC	A	Toe Nails	None	Other	3.2352	2.7033	1.8877	1.5700	1.6341	1.5309	0.8722	0.8292	3.2265	2.8654	2.1145	1.9101	1.7596	1.6910	1.1113	1.0857	2.0165	1.7014	1.4494	1.2413	1.3103	1.2401	0.8586	0.8230	2.1084	1.8874	1.7088	1.5733	1.4115	1.3691	1.0857	1.0650
				Wood	2.9615	2.4610	1.7166	1.4228	1.5681	1.4743	0.8295	0.7904	2.9835	2.6406	1.9715	1.7826	1.6936	1.6289	1.0741	1.0501	1.8027	1.5144	1.3031	1.1093	1.2384	1.1737	0.8069	0.7761	1.9156	1.7117	1.5840	1.4568	1.3261	1.2889	1.0379	1.0181
			Hurricane	Other	2.7894	2.2274	1.5875	1.2734	1.2782	1.1783	0.7732	0.7357	2.9081	2.5409	1.8625	1.6632	1.5836	1.5209	1.0395	1.0175	1.5794	1.2679	1.1789	0.9812	0.9900	0.9288	0.7399	0.7127	1.8137	1.6040	1.4827	1.3575	1.2452	1.2051	0.9981	0.9803
				Wood	2.5649	2.0343	1.4655	1.1689	1.1909	1.0929	0.7392	0.7033	2.7328	2.3873	1.7616	1.5768	1.5354	1.4753	1.0171	0.9977	1.4060	1.1194	1.0776	0.8997	0.9007	0.8434	0.7046	0.6817	1.6817	1.4882	1.3999	1.2828	1.1977	1.1621	0.9744	0.9589
		Clips	None	Other	3.1191	2.5474	1.8829	1.5587	1.4287	1.3161	0.8564	0.8127	3.2028	2.8392	2.1126	1.9075	1.7383	1.6703	1.1113	1.0848	1.8661	1.5251	1.4400	1.2274	1.1191	1.0427	0.8379	0.8023	2.0861	1.8648	1.7059	1.5704	1.3905	1.3433	1.0848	1.0637
				Wood	2.8208	2.2786	1.7124	1.4067	1.3478	1.2452	0.8075	0.7684	2.9554	2.6056	1.9699	1.7781	1.6635	1.6005	1.0741	1.0501	1.6341	1.3290	1.2921	1.0941	1.0168	0.9511	0.7807	0.7486	1.8949	1.6868	1.5778	1.4513	1.2951	1.2546	1.0359	1.0162
			Hurricane	Other	2.7671	2.1948	1.5862	1.2724	1.2187	1.1126	0.7590	0.7221	2.9075	2.5390	1.8619	1.6629	1.5785	1.5160	1.0359	1.0142	1.5471	1.2245	1.1776	0.9809	0.9317	0.8619	0.7292	0.7011	1.8111	1.6011	1.4827	1.3575	1.2401	1.1990	0.9971	0.9793
				Wood	2.5568	2.0142	1.4652	1.1689	1.1556	1.0582	0.7321	0.6991	2.7328	2.3869	1.7616	1.5768	1.5332	1.4720	1.0159	0.9964	1.3843	1.0958	1.0747	0.8984	0.8712	0.8085	0.6982	0.6739	1.6771	1.4850	1.3999	1.2828	1.1931	1.1582	0.9735	0.9589
		Wraps	None	Other	3.1035	2.5390	1.8829	1.5587	1.4177	1.3086	0.8564	0.8127	3.2006	2.8369	2.1126	1.9075	1.7373	1.6703	1.1113	1.0848	1.8583	1.5147	1.4400	1.2274	1.1132	1.0333	0.8379	0.8023	2.0851	1.8609	1.7059	1.5704	1.3895	1.3423	1.0848	1.0637
				Wood	2.8149	2.2786	1.7124	1.4067	1.3326	1.2365	0.8075	0.7684	2.9524	2.6008	1.9696	1.7781	1.6619	1.6005	1.0741	1.0501	1.6292	1.3180	1.2921	1.0941	1.0061	0.9346	0.7807	0.7486	1.8949	1.6800	1.5778	1.4513	1.2951	1.2546	1.0359	1.0162
			Hurricane	Other	2.7671	2.1938	1.5862	1.2724	1.2151	1.1093	0.7590	0.7218	2.9055	2.5387	1.8619	1.6629	1.5785	1.5137	1.0359	1.0142	1.5471	1.2236	1.1776	0.9809	0.9259	0.8564	0.7289	0.7007	1.8111	1.6008	1.4827	1.3575	1.2401	1.1970	0.9971	0.9793
				Wood	2.5568	2.0142	1.4652	1.1689	1.1553	1.0582	0.7321	0.6985	2.7328	2.3869	1.7616	1.5768	1.5332	1.4714	1.0159	0.9964	1.3843	1.0958	1.0747	0.8984	0.8677	0.8082	0.6982	0.6739	1.6771	1.4850	1.3999	1.2828	1.1931	1.1572	0.9735	0.9589
	B	Toe Nails	None	Other	2.1773	1.8014	1.4795	1.1977	1.3821	1.3106	0.8211	0.7874	2.2511	1.9356	1.7706	1.5746	1.4943	1.4393	1.0702	1.0485	1.8424	1.5671	1.3206	1.1288	1.2656	1.2035	0.8266	0.7942	1.9214	1.7088	1.5950	1.4639	1.3458	1.3035	1.0615	1.0424
				Wood	2.0162	1.6613	1.3623	1.1123	1.3555	1.2896	0.7810	0.7528	2.1116	1.8156	1.6720	1.4905	1.4500	1.4041	1.0349	1.0155	1.6548	1.4076	1.1954	1.0220	1.2048	1.1482	0.7790	0.7535	1.7583	1.5632	1.4795	1.3610	1.2692	1.2310	1.0123	0.9958
			Hurricane	Other	1.6865	1.3135	1.2177	0.9621	1.0443	0.9806	0.7425	0.7156	1.9554	1.6555	1.5814	1.4038	1.3769	1.3258	1.0120	0.9948	1.3850	1.1258	1.0657	0.9004	0.9499	0.9013	0.7250	0.6995	1.6315	1.4390	1.4021	1.2892	1.1996	1.1640	0.9786	0.9634
				Wood	1.5260	1.1663	1.1423	0.9088	0.9618	0.9007	0.7101	0.6865	1.8570	1.5804	1.5238	1.3610	1.3471	1.2960	0.9971	0.9806	1.2284	0.9932	0.9867	0.8441	0.8625	0.8133	0.6936	0.6716	1.5215	1.3523	1.3387	1.2368	1.1598	1.1262	0.9599	0.9476
		Clips	None	Other	1.8463	1.3772	1.4057	1.0919	1.0537	0.9673	0.7839	0.7464	2.1634	1.8234	1.7561	1.5412	1.4345	1.3769	1.0660	1.0443	1.6082	1.2850	1.2798	1.0712	1.0175	0.9444	0.7968	0.7603	1.8648	1.6364	1.5840	1.4484	1.3041	1.2582	1.0566	1.0349
				Wood	1.6742	1.2559	1.2873	1.0019	1.0000	0.9262	0.7402	0.7098	2.0129	1.7043	1.6577	1.4542	1.3805	1.3319	1.0294	1.0113	1.4148	1.1317	1.1453	0.9576	0.9246	0.8635	0.7396	0.7072	1.6923	1.4872	1.4662	1.3387	1.2138	1.1783	1.0055	0.9867
			Hurricane	Other	1.5400	1.1000	1.1999	0.9356	0.9291	0.8583	0.7147	0.6852	1.9308	1.6218	1.5791	1.4005	1.3507	1.2957	1.0097	0.9884	1.2983	1.0078	1.0634	0.8942	0.8602	0.8030	0.7040	0.6794	1.6166	1.4232	1.4021	1.2892	1.1783	1.1401	0.9731	0.9589
				Wood	1.4238	1.0265	1.1291	0.8945	0.9004	0.8350	0.7001	0.6729	1.8386	1.5603	1.5231	1.3591	1.3264	1.2805	0.9961	0.9803	1.1695	0.9204	0.9861	0.8402	0.8153	0.7625	0.6849	0.6639	1.5105	1.3426	1.3387	1.2368	1.1475	1.1158	0.9554	0.9447
		Wraps	None	Other	1.7894	1.2941	1.4057	1.0841	1.0181	0.9233	0.7836	0.7444	2.1482	1.8023	1.7519	1.5357	1.4290	1.3672	1.0654	1.0437	1.5671	1.2203	1.2795	1.0657	0.9841	0.9055	0.7949	0.7583	1.8525	1.6189	1.5836	1.4484	1.2980	1.2498	1.0566	1.0349
				Wood	1.6124	1.1643	1.2873	0.9932	0.9518	0.8729	0.7396	0.7075	1.9955	1.6826	1.6529	1.4484	1.3743	1.3200	1.0275	1.0100	1.3675	1.0592	1.1420	0.9479	0.8787	0.8133	0.7354	0.7053	1.6768	1.4646	1.4662	1.3387	1.2074	1.1679	1.0055	0.9867
			Hurricane	Other	1.5296	1.0780	1.1999	0.9356	0.9185	0.8392	0.7147	0.6836	1.9308	1.6144	1.5768	1.3995	1.3455	1.2918	1.0081	0.9880	1.2908	0.9974	1.0628	0.8929	0.8450	0.7842	0.7027	0.6778	1.6157	1.4209	1.4018	1.2879	1.1779	1.1398	0.9731	0.9589
				Wood	1.4138	1.0100	1.1291	0.8939	0.8945	0.8221	0.6991	0.6729	1.8386	1.5500	1.5215	1.3585	1.3245	1.2763	0.9961	0.9799	1.1621	0.9136	0.9851	0.8399	0.8078	0.7567	0.6823	0.6629	1.5099	1.3387	1.3387	1.2368	1.1472	1.1158	0.9554	0.9447
	C	Toe Nails	None	Other	2.1440	1.7891	1.4791	1.1977	1.3730	1.3051	0.8204	0.7874	2.1847	1.9007	1.7706	1.5723	1.4808	1.4306	1.0702	1.0479	1.8373	1.5639	1.3200	1.1265	1.2640	1.2025	0.8266	0.7942	1.9191	1.7075	1.5937	1.4639	1.3458	1.3022	1.0615	1.0424
				Wood	1.9780	1.6445	1.3623	1.1123	1.3439	1.2815	0.7803	0.7528	2.0579	1.7975	1.6720	1.4898	1.4439	1.3953	1.0349	1.0149	1.6529	1.4050	1.1951	1.0197	1.2019	1.1462	0.7790	0.7535	1.7551	1.5632	1.4769	1.3604	1.2688	1.2310	1.0123	0.9958
			Hurricane	Other	1.6428	1.2993	1.2138	0.9612	1.0379	0.9799	0.7409	0.7137	1.8910	1.6263	1.5775	1.4038	1.3633	1.3167	1.0120	0.9948	1.3818	1.1258	1.0657	0.9004	0.9489	0.9004	0.7240	0.6995	1.6270	1.4374	1.4008	1.2892	1.1996	1.1640	0.9777	0.9634
				Wood	1.4824	1.1521	1.1343	0.9029	0.9541	0.8978	0.7101	0.6846	1.7988	1.5590	1.5192	1.3610	1.3326	1.2896	0.9971	0.9806	1.2229	0.9906	0.9867	0.8441	0.8599	0.8114	0.6927	0.6716	1.5189	1.3494	1.3378	1.2352	1.1598	1.1258	0.9596	0.9476
		Clips	None	Other	1.7599	1.3261	1.4012	1.0844	1.0379	0.9596	0.7829	0.7444	2.0854	1.7690	1.7464	1.5312	1.4180	1.3636	1.0624	1.0391	1.6060	1.2779	1.2798	1.0712	1.0175	0.9444	0.7968	0.7603	1.8602	1.6335	1.5836	1.4471	1.3041	1.2582	1.0566	1.0349
				Wood	1.6095	1.2177	1.2815	0.9955	0.9858	0.9201	0.7392	0.7075	1.9508	1.6587	1.6445	1.4432	1.3630	1.3158	1.0246	1.0032	1.4148	1.1275	1.1453	0.9576	0.9227	0.8635	0.7389	0.7072	1.6923	1.4824	1.4662	1.3387	1.2138	1.1776	1.0055	0.9867
			Hurricane	Other	1.4555	1.0657	1.1957	0.9301	0.9227	0.8547	0.7147	0.6852	1.8560	1.5781	1.5749	1.3976	1.3403	1.2905	1.0084	0.9884	1.2905	1.0058	1.0608	0.8942	0.8602	0.8030	0.7037	0.6791	1.6124	1.4183	1.3966	1.2873	1.1783	1.1401	0.9731	0.9589
				Wood	1.3523	1.0000	1.1262	0.8910	0.8936	0.8305	0.6995	0.6729	1.7800	1.5270	1.5176	1.3588	1.3235	1.2802	0.9961	0.9783	1.1605	0.9152	0.9835	0.8402	0.8153	0.7625	0.6833	0.6639	1.5105	1.3371	1.3352	1.2349	1.1475	1.1158	0.9554	0.9447
		Wraps	None	Other	1.6901	1.2303	1.3898	1.0660	0.9971	0.9107	0.7819	0.7434	2.0624	1.7347	1.7434	1.5247	1.4128	1.3530	1.0624	1.0388	1.5629	1.2155	1.2740	1.0621	0.9829	0.9055	0.7949	0.7580	1.8499	1.6157	1.5794	1.4448	1.2973	1.2498	1.0566	1.0349
				Wood	1.5235	1.1207	1.2698	0.9770	0.9366	0.8619	0.7370	0.7066	1.9249	1.6247	1.6402	1.4387	1.3594	1.3064	1.0246	1.0029	1.3630	1.0521	1.1420	0.9479	0.8764	0.8133	0.7344	0.7043	1.6749	1.4604	1.4597	1.3387	1.2035	1.1650	1.0055	0.9867
			Hurricane	Other	1.4400	1.0398	1.1935	0.9282	0.9013	0.8305	0.7130	0.6836	1.8554	1.5723	1.5720	1.3953	1.3326	1.2841	1.0081	0.9877	1.2837	0.9929	1.0599	0.8929	0.8428	0.7819	0.7024	0.6768	1.6111	1.4131	1.3963	1.2873	1.1776	1.1391	0.9731	0.9583
				Wood	1.3413	0.9887	1.1242	0.8900	0.8822	0.8159	0.6991	0.6729	1.7800	1.5257	1.5147	1.3543	1.3161	1.2734	0.9961	0.9783	1.1572	0.9097	0.9816	0.8395	0.8062	0.7541	0.6823	0.6626	1.5057	1.3310	1.3352	1.2349	1.1459	1.1148	0.9554	0.9437

Table 4-6. Terrain B Loss Relativities: (FBC Roof Cover) Normalized to Typical House

Terrain B Single Family					Low Roof Slope (<= 5.12)														Other Roof Slope (>=6:12)											
					Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile				Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile			
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip	
					No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
FBC	A	Toe Nails	None	Other	2.3562	2.3048	1.2572	1.2352	1.2255	1.2022	0.5995	0.5959	2.2316	2.1948	1.3860	1.3662	1.1854	1.1753	0.7379	0.7360	1.4400	1.4067	0.9848	0.9719	0.9916	0.9751	0.6030	0.6008	1.4322	1.4138	1.1491	1.1375	0.9641	0.9566	0.7360	0.7308
				Wood	2.1184	2.0696	1.1161	1.0938	1.1757	1.1498	0.5600	0.5561	2.0171	1.9819	1.2688	1.2504	1.1301	1.1187	0.7017	0.7004	1.2549	1.2184	0.8538	0.8415	0.9337	0.9139	0.5577	0.5535	1.2698	1.2520	1.0359	1.0265	0.8894	0.8839	0.6930	0.6885
			Hurricane	Other	1.8619	1.8253	0.9602	0.9405	0.8602	0.8512	0.4934	0.4898	1.9007	1.8651	1.1553	1.1388	1.0120	1.0084	0.6703	0.6684	0.9926	0.9660	0.7179	0.7059	0.6600	0.6535	0.4801	0.4791	1.1517	1.1323	0.9414	0.9285	0.8098	0.8049	0.6519	0.6519
				Wood	1.6716	1.6367	0.8641	0.8431	0.7680	0.7616	0.4623	0.4588	1.7577	1.7227	1.0786	1.0605	0.9683	0.9657	0.6503	0.6490	0.8382	0.8127	0.6360	0.6237	0.5691	0.5649	0.4478	0.4448	1.0427	1.0233	0.8754	0.8632	0.7638	0.7612	0.6325	0.6325
		Clips	None	Other	2.1737	2.1394	1.2417	1.2242	0.9900	0.9848	0.5788	0.5765	2.1886	2.1537	1.3840	1.3646	1.1508	1.1472	0.7344	0.7315	1.2449	1.2210	0.9667	0.9554	0.7800	0.7739	0.5823	0.5797	1.3979	1.3772	1.1453	1.1359	0.9327	0.9282	0.7308	0.7305
				Wood	1.9181	1.8832	1.1006	1.0831	0.9185	0.9133	0.5332	0.5322	1.9712	1.9376	1.2659	1.2485	1.0870	1.0835	0.6991	0.6969	1.0482	1.0256	0.8360	0.8250	0.6878	0.6810	0.5299	0.5283	1.2300	1.2074	1.0349	1.0259	0.8518	0.8470	0.6875	0.6875
			Hurricane	Other	1.8133	1.7781	0.9579	0.9395	0.7865	0.7803	0.4798	0.4765	1.8994	1.8638	1.1550	1.1381	1.0010	0.9984	0.6671	0.6671	0.9440	0.9194	0.7169	0.7033	0.5882	0.5849	0.4665	0.4662	1.1498	1.1297	0.9408	0.9279	0.7952	0.7926	0.6512	0.6512
				Wood	1.6448	1.6079	0.8596	0.8405	0.7315	0.7282	0.4575	0.4542	1.7561	1.7221	1.0783	1.0602	0.9615	0.9583	0.6487	0.6487	0.8124	0.7887	0.6360	0.6212	0.5370	0.5348	0.4403	0.4390	1.0427	1.0233	0.8751	0.8632	0.7590	0.7570	0.6322	0.6318
		Wraps	None	Other	2.1592	2.1223	1.2417	1.2236	0.9754	0.9715	0.5781	0.5759	2.1886	2.1527	1.3840	1.3646	1.1478	1.1449	0.7344	0.7315	1.2291	1.2058	0.9657	0.9550	0.7622	0.7587	0.5817	0.5797	1.3953	1.3763	1.1453	1.1359	0.9317	0.9282	0.7308	0.7305
				Wood	1.9016	1.8674	1.0996	1.0815	0.9000	0.8968	0.5322	0.5312	1.9706	1.9359	1.2659	1.2485	1.0831	1.0815	0.6991	0.6969	1.0298	1.0065	0.8340	0.8240	0.6671	0.6632	0.5286	0.5283	1.2268	1.2074	1.0349	1.0256	0.8509	0.8470	0.6875	0.6875
			Hurricane	Other	1.8062	1.7729	0.9576	0.9395	0.7816	0.7761	0.4798	0.4765	1.8981	1.8625	1.1550	1.1381	1.0010	0.9971	0.6671	0.6671	0.9431	0.9194	0.7169	0.7033	0.5817	0.5794	0.4662	0.4662	1.1495	1.1294	0.9408	0.9279	0.7939	0.7926	0.6512	0.6512
				Wood	1.6445	1.6079	0.8596	0.8405	0.7299	0.7263	0.4575	0.4542	1.7548	1.7221	1.0783	1.0602	0.9615	0.9573	0.6487	0.6487	0.8107	0.7878	0.6360	0.6212	0.5328	0.5306	0.4403	0.4390	1.0427	1.0233	0.8751	0.8632	0.7580	0.7561	0.6322	0.6318
	B	Toe Nails	None	Other	1.5332	1.4833	0.9346	0.9110	1.0314	1.0084	0.5610	0.5571	1.4513	1.4089	1.1307	1.1097	0.9605	0.9521	0.7037	0.7014	1.3148	1.2841	0.8887	0.8767	0.9612	0.9456	0.5794	0.5755	1.2993	1.2756	1.0628	1.0518	0.9169	0.9104	0.7143	0.7137
				Wood	1.3895	1.3397	0.8502	0.8282	1.0049	0.9806	0.5257	0.5215	1.3355	1.2941	1.0518	1.0314	0.9256	0.9156	0.6729	0.6697	1.1508	1.1207	0.7784	0.7651	0.9000	0.8822	0.5361	0.5322	1.1608	1.1346	0.9638	0.9515	0.8531	0.8444	0.6745	0.6732
			Hurricane	Other	1.0324	0.9929	0.6852	0.6635	0.6771	0.6681	0.4765	0.4736	1.1731	1.1362	0.9621	0.9418	0.8428	0.8340	0.6532	0.6532	0.8638	0.8437	0.6461	0.6335	0.6393	0.6318	0.4714	0.4685	1.0304	1.0110	0.8919	0.8816	0.7774	0.7732	0.6415	0.6406
				Wood	0.8835	0.8441	0.6309	0.6092	0.5904	0.5843	0.4471	0.4458	1.0961	1.0621	0.9194	0.9020	0.8146	0.8075	0.6390	0.6390	0.7231	0.7062	0.5859	0.5752	0.5480	0.5425	0.4403	0.4380	0.9447	0.9259	0.8418	0.8340	0.7399	0.7376	0.6280	0.6260
		Clips	None	Other	1.1084	1.0560	0.8344	0.8039	0.6703	0.6619	0.5189	0.5163	1.3491	1.3060	1.1000	1.0770	0.8894	0.8835	0.6972	0.6949	1.0353	1.0055	0.8314	0.8140	0.6904	0.6852	0.5429	0.5412	1.2300	1.2019	1.0469	1.0362	0.8648	0.8612	0.7069	0.7069
				Wood	0.9848	0.9346	0.7431	0.7121	0.6270	0.6199	0.4814	0.4782	1.2307	1.1915	1.0126	0.9896	0.8437	0.8405	0.6645	0.6645	0.8787	0.8505	0.7143	0.6985	0.6047	0.5998	0.4901	0.4892	1.0806	1.0560	0.9440	0.9340	0.7878	0.7839	0.6639	0.6639
			Hurricane	Other	0.8340	0.7794	0.6648	0.6396	0.5555	0.5490	0.4435	0.4429	1.1414	1.1013	0.9570	0.9363	0.8127	0.8072	0.6457	0.6454	0.7499	0.7227	0.6402	0.6280	0.5380	0.5335	0.4458	0.4442	1.0155	0.9942	0.8884	0.8784	0.7515	0.7493	0.6370	0.6360
				Wood	0.7561	0.7059	0.6179	0.5969	0.5306	0.5228	0.4319	0.4313	1.0744	1.0421	0.9152	0.8958	0.7955	0.7897	0.6364	0.6360	0.6558	0.6318	0.5827	0.5717	0.4979	0.4943	0.4309	0.4290	0.9337	0.9156	0.8386	0.8308	0.7276	0.7266	0.6263	0.6247
		Wraps	None	Other	1.0307	0.9744	0.8279	0.7936	0.6267	0.6182	0.5173	0.5144	1.3274	1.2811	1.0964	1.0718	0.8800	0.8751	0.6972	0.6949	0.9793	0.9424	0.8263	0.8098	0.6538	0.6464	0.5416	0.5396	1.2138	1.1851	1.0453	1.0324	0.8573	0.8531	0.7062	0.7059
				Wood	0.9020	0.8460	0.7334	0.7004	0.5742	0.5675	0.4788	0.4756	1.2058	1.1624	1.0110	0.9880	0.8321	0.8298	0.6645	0.6645	0.8082	0.7742	0.7092	0.6914	0.5613	0.5526	0.4872	0.4856	1.0608	1.0336	0.9414	0.9314	0.7755	0.7726	0.6626	0.6626
			Hurricane	Other	0.8214	0.7580	0.6632	0.6377	0.5351	0.5273	0.4416	0.4410	1.1381	1.0984	0.9554	0.9350	0.8075	0.8020	0.6454	0.6445	0.7409	0.7111	0.6386	0.6257	0.5186	0.5144	0.4452	0.4439	1.0100	0.9903	0.8877	0.8784	0.7470	0.7454	0.6367	0.6360
				Wood	0.7480	0.6914	0.6173	0.5962	0.5170	0.5105	0.4313	0.4313	1.0744	1.0404	0.9139	0.8945	0.7926	0.7887	0.6364	0.6360	0.6477	0.6228	0.5804	0.5704	0.4901	0.4875	0.4306	0.4290	0.9314	0.9126	0.8376	0.8308	0.7273	0.7247	0.6260	0.6247
	C	Toe Nails	None	Other	1.5163	1.4678	0.9343	0.9104	1.0265	1.0039	0.5610	0.5571	1.4225	1.3869	1.1288	1.1061	0.9531	0.9447	0.7037	0.7014	1.3148	1.2841	0.8871	0.8748	0.9612	0.9444	0.5794	0.5755	1.2986	1.2750	1.0605	1.0492	0.9159	0.9104	0.7143	0.7124
				Wood	1.3756	1.3268	0.8502	0.8282	1.0049	0.9806	0.5257	0.5215	1.3174	1.2808	1.0508	1.0262	0.9227	0.9123	0.6729	0.6697	1.1508	1.1207	0.7761	0.7642	0.9000	0.8822	0.5361	0.5322	1.1556	1.1323	0.9592	0.9466	0.8525	0.8444	0.6745	0.6732
			Hurricane	Other	1.0058	0.9722	0.6842	0.6635	0.6771	0.6677	0.4765	0.4736	1.1411	1.1119	0.9570	0.9411	0.8357	0.8327	0.6532	0.6532	0.8638	0.8437	0.6457	0.6335	0.6380	0.6309	0.4710	0.4685	1.0294	1.0110	0.8900	0.8803	0.7768	0.7726	0.6415	0.6406
				Wood	0.8625	0.8298	0.6280	0.6092	0.5904	0.5843	0.4471	0.4458	1.0709	1.0440	0.9143	0.9020	0.8098	0.8062	0.6390	0.6390	0.7227	0.7062	0.5856	0.5752	0.5471	0.5425	0.4397	0.4380	0.9431	0.9259	0.8418	0.8305	0.7396	0.7360	0.6280	0.6260
		Clips	None	Other	1.0576	1.0142	0.8266	0.7946	0.6600	0.6551	0.5183	0.5160	1.2996	1.2595	1.0925	1.0696	0.8780	0.8722	0.6972	0.6949	1.0330	1.0039	0.8295	0.8130	0.6904	0.6852	0.5425	0.5406	1.2248	1.2009	1.0424	1.0330	0.8641	0.8609	0.7069	0.7069
				Wood	0.9479	0.9055	0.7354	0.7049	0.6221	0.6176	0.4808	0.4782	1.1896	1.1511	1.0091	0.9838	0.8373	0.8327	0.6645	0.6645	0.8748	0.8470	0.7121	0.6962	0.6047	0.5998	0.4898	0.4882	1.0776	1.0544	0.9401	0.9311	0.7868	0.7839	0.6639	0.6639
			Hurricane	Other	0.7858	0.7434	0.6577	0.6347	0.5497	0.5432	0.4435	0.4429	1.0971	1.0679	0.9524	0.9337	0.8052	0.8017	0.6457	0.6451	0.7480	0.7221	0.6402	0.6280	0.5380	0.5335	0.4458	0.4442	1.0113	0.9903	0.8871	0.8784	0.7515	0.7493	0.6370	0.6357
				Wood	0.7192	0.6794	0.6127	0.5953	0.5247	0.5189	0.4319	0.4313	1.0401	1.0152	0.9110	0.8936	0.7923	0.7887	0.6364	0.6360	0.6512	0.6309	0.5827	0.5717	0.4979	0.4940	0.4306	0.4290	0.9324	0.9143	0.8386	0.8305	0.7276	0.7263	0.6257	0.6247
		Wraps	None	Other	0.9644	0.9094	0.8143	0.7790	0.6118	0.6040	0.5173	0.5128	1.2669	1.2239	1.0844	1.0624	0.8690	0.8638	0.6969	0.6949	0.9725	0.9366	0.8221	0.8039	0.6538	0.6464	0.5416	0.5383	1.2093	1.1821	1.0391	1.0262	0.8551	0.8509	0.7062	0.7053
				Wood	0.8483	0.7972	0.7189	0.6872	0.5645	0.5577	0.4788	0.4749	1.1572	1.1145	1.0013	0.9799	0.8266	0.8221	0.6645	0.6642	0.8049	0.7713	0.7030	0.6849	0.5597	0.5526	0.4872	0.4850	1.0569	1.0304	0.9366	0.9227	0.7745	0.7722	0.6626	0.6610
			Hurricane	Other	0.7609	0.7147	0.6571	0.6318	0.5254	0.5199	0.4416	0.4410	1.0932	1.0579	0.9524	0.9334	0.7972	0.7952	0.6454	0.6445	0.7367	0.7101	0.6386	0.6257	0.5183	0.5137	0.4452	0.4435	1.0100	0.9890	0.8868	0.8784	0.7470	0.7451	0.6367	0.6351
				Wood	0.7014	0.6632	0.6105	0.5927	0.5095	0.5057	0.4313	0.4313	1.0401	1.0081	0.9110	0.8932	0.7862	0.7849	0.6364	0.6360	0.6448	0.6228	0.5804	0.5704	0.4901	0.4863	0.4306	0.4287	0.9314	0.9114	0.8376	0.8305	0.7273	0.7244	0.6257	0.6244

Table 4-7. Terrain C Loss Relativities: (Non FBC Roof Cover) Normalized to Typical House

Terrain C Single Family					Low Roof Slope (<= 5.12)												Other Roof Slope (>=6:12)															
					Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile				Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile			
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip	
					No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
Non-FBC	A	Toe Nails	None	Other	3.0941	2.7683	2.0306	1.7946	1.9001	1.7791	1.0523	0.9901	2.8323	2.5919	2.0074	1.8434	1.7667	1.6829	1.1188	1.0770	2.2933	2.0941	1.5582	1.4025	1.6222	1.5402	1.0118	0.9638	1.9657	1.8137	1.5566	1.4496	1.4428	1.3892	1.0755	1.0455
				Wood	2.7710	2.4585	1.8014	1.5845	1.5693	1.4542	0.9097	0.8583	2.5195	2.2887	1.8023	1.6485	1.5464	1.4675	0.9935	0.9567	2.1064	1.9304	1.3803	1.2404	1.3512	1.2809	0.8883	0.8521	1.7602	1.6200	1.3834	1.2831	1.2543	1.2085	0.9548	0.9298
			Hurricane	Other	2.2701	1.8688	1.3818	1.1024	1.3506	1.2271	0.8035	0.7454	2.2135	1.9375	1.4700	1.2856	1.4208	1.3373	0.9264	0.8855	1.2794	1.0545	0.9378	0.7667	1.0882	1.0189	0.7333	0.6931	1.3360	1.1757	1.0854	0.9749	1.1040	1.0560	0.8571	0.8320
				Wood	1.8731	1.4669	1.0956	0.8317	0.9663	0.8407	0.5393	0.4842	1.8899	1.6210	1.2299	1.0575	1.1776	1.0950	0.7652	0.7277	0.9338	0.7305	0.6989	0.5554	0.6235	0.5606	0.4845	0.4527	1.0709	0.9285	0.8840	0.7887	0.8357	0.7958	0.7014	0.6819
		Clips	None	Other	2.8184	2.4700	1.9712	1.7348	1.5690	1.4489	0.9632	0.8985	2.7364	2.4944	1.9954	1.8351	1.6788	1.5984	1.1018	1.0603	1.8728	1.6513	1.4752	1.3122	1.2741	1.1925	0.9248	0.8775	1.8481	1.6952	1.5424	1.4372	1.3571	1.3063	1.0566	1.0288
				Wood	2.4530	2.1114	1.7265	1.5077	1.3131	1.2024	0.8032	0.7525	2.4028	2.1674	1.7840	1.6337	1.4530	1.3781	0.9703	0.9366	1.6256	1.4285	1.2794	1.1321	1.0455	0.9827	0.7751	0.7410	1.6163	1.4765	1.3660	1.2676	1.1532	1.1105	0.9279	0.9056
			Hurricane	Other	2.2150	1.7995	1.3778	1.0981	1.2051	1.0761	0.7274	0.6655	2.2135	1.9341	1.4700	1.2856	1.3756	1.2908	0.9097	0.8694	1.2243	0.9793	0.9363	0.7624	0.8991	0.8249	0.6699	0.6287	1.3314	1.1711	1.0845	0.9743	1.0504	1.0034	0.8484	0.8239
				Wood	1.8515	1.4431	1.0963	0.8311	0.9446	0.8181	0.5356	0.4802	1.8899	1.6207	1.2293	1.0572	1.1748	1.0903	0.7642	0.7268	0.9196	0.7095	0.6974	0.5526	0.6049	0.5415	0.4827	0.4496	1.0678	0.9285	0.8824	0.7877	0.8338	0.7915	0.7014	0.6816
		Wraps	None	Other	2.7748	2.4230	1.9703	1.7327	1.5238	1.4044	0.9588	0.8957	2.7237	2.4848	1.9954	1.8351	1.6662	1.5854	1.1018	1.0600	1.8100	1.5811	1.4749	1.3122	1.2287	1.1482	0.9245	0.8759	1.8385	1.6860	1.5421	1.4369	1.3502	1.2998	1.0566	1.0288
				Wood	2.4004	2.0563	1.7240	1.5040	1.2528	1.1457	0.7952	0.7463	2.3874	2.1535	1.7840	1.6337	1.4325	1.3586	0.9703	0.9363	1.5405	1.3379	1.2785	1.1312	0.9817	0.9196	0.7732	0.7382	1.6040	1.4650	1.3660	1.2676	1.1389	1.0972	0.9279	0.9056
			Hurricane	Other	2.2150	1.7995	1.3778	1.0981	1.1776	1.0483	0.7274	0.6646	2.2135	1.9341	1.4700	1.2853	1.3697	1.2859	0.9097	0.8691	1.2234	0.9771	0.9363	0.7621	0.8666	0.7952	0.6689	0.6267	1.3308	1.1708	1.0845	0.9743	1.0480	1.0006	0.8484	0.8239
				Wood	1.8515	1.4431	1.0950	0.8311	0.9403	0.8144	0.5356	0.4802	1.8899	1.6204	1.2293	1.0569	1.1739	1.0903	0.7642	0.7268	0.9196	0.7082	0.6974	0.5520	0.6024	0.5399	0.4827	0.4496	1.0671	0.9285	0.8824	0.7877	0.8338	0.7915	0.7011	0.6816
	B	Toe Nails	None	Other	2.4554	2.1878	1.6569	1.4177	1.6584	1.5582	0.9756	0.9149	2.1111	1.8629	1.5842	1.3905	1.4579	1.3769	1.0192	0.9768	2.1856	1.9988	1.4127	1.2534	1.5811	1.5028	0.9613	0.9103	1.7952	1.6371	1.3852	1.2679	1.3515	1.2930	1.0059	0.9740
				Wood	2.2562	2.0220	1.5084	1.3140	1.3629	1.2769	0.8679	0.8230	1.9322	1.7194	1.4313	1.2590	1.3175	1.2519	0.9137	0.8821	2.0223	1.8654	1.2587	1.1207	1.3252	1.2614	0.8605	0.8233	1.6179	1.4802	1.2188	1.1111	1.1909	1.1451	0.8868	0.8608
			Hurricane	Other	1.4199	1.1210	0.9511	0.6959	1.0910	1.0090	0.7460	0.6959	1.3889	1.1188	1.1145	0.9325	1.1522	1.0811	0.8543	0.8193	1.1027	0.9093	0.8097	0.6544	1.0470	0.9093	0.6965	0.6544	1.1371	0.9827	0.9864	0.8868	1.0260	0.9805	0.8125	0.7881
				Wood	1.0226	0.7488	0.7256	0.5294	0.6748	0.5962	0.4935	0.4524	1.1315	0.9025	0.9421	0.8004	0.9158	0.8524	0.7262	0.6983	0.7624	0.6043	0.6077	0.4972	0.5690	0.5226	0.4660	0.4403	0.9038	0.7843	0.8190	0.7429	0.7782	0.7438	0.6881	0.6702
		Clips	None	Other	1.8920	1.5353	1.3537	1.0260	1.1563	1.0343	0.7837	0.7008	1.8376	1.5483	1.4675	1.2367	1.2803	1.1884	0.9641	0.9149	1.6324	1.3917	1.1925	0.9916	1.1426	1.0495	0.7983	0.7370	1.5702	1.3830	1.3066	1.1714	1.2051	1.1420	0.9567	0.9233
				Wood	1.6770	1.3849	1.1581	0.8716	1.0000	0.9134	0.6402	0.5832	1.6272	1.3728	1.2905	1.0804	1.1278	1.0575	0.8379	0.8011	1.4242	1.2256	0.9972	0.8134	0.9524	0.8923	0.6380	0.5962	1.3496	1.1829	1.1296	1.0006	1.0093	0.9629	0.8131	0.7859
			Hurricane	Other	1.1959	0.8026	0.9226	0.6482	0.8419	0.7407	0.6021	0.5393	1.3533	1.0622	1.1089	0.9233	1.0458	0.9666	0.8150	0.7760	0.9644	0.7293	0.7992	0.6408	0.7874	0.7181	0.5879	0.5433	1.1142	0.9527	0.9814	0.8796	0.9338	0.8640	0.7908	0.7630
				Wood	0.9090	0.5925	0.7141	0.5158	0.6095	0.5217	0.4827	0.4412	1.1176	0.8812	0.9363	0.7921	0.9025	0.8403	0.7243	0.6968	0.6989	0.5297	0.6009	0.4889	0.5282	0.4777	0.4592	0.4341	0.8923	0.7732	0.8100	0.7308	0.7720	0.7379	0.6875	0.6680
		Wraps	None	Other	1.6726	1.2413	1.3156	0.9579	1.0149	0.8648	0.7630	0.6717	1.7624	1.4387	1.4477	1.2061	1.2339	1.1343	0.9520	0.9010	1.4338	1.1411	1.1566	0.9291	1.0118	0.8998	0.7744	0.7070	1.5096	1.3041	1.2893	1.1476	1.1612	1.0953	0.9455	0.9109
				Wood	1.4177	1.0464	1.1129	0.7933	0.8292	0.7228	0.6095	0.5421	1.5340	1.2420	1.2695	1.0483	1.0640	0.9870	0.8209	0.7791	1.1804	0.9282	0.9607	0.7503	0.7757	0.7017	0.5990	0.5486	1.2763	1.0888	1.1120	0.9796	0.9446	0.8951	0.7952	0.7667
			Hurricane	Other	1.1807	0.7676	0.9220	0.6451	0.7559	0.6349	0.5931	0.5244	1.3502	1.0541	1.1064	0.9205	1.0232	0.9394	0.8122	0.7717	0.9558	0.7092	0.7961	0.6349	0.7042	0.6194	0.5804	0.5328	1.1126	0.9486	0.9796	0.8781	0.9127	0.8595	0.7884	0.7605
				Wood	0.9059	0.5798	0.7101	0.5090	0.6009	0.5108	0.4817	0.4403	1.1157	0.8756	0.9335	0.7884	0.9019	0.8376	0.7218	0.6952	0.6928	0.5207	0.5959	0.4811	0.5207	0.4688	0.4582	0.4313	0.8883	0.7670	0.8072	0.7296	0.7701	0.7348	0.6863	0.6671
	C	Toe Nails	None	Other	2.4372	2.1804	1.6569	1.4174	1.6494	1.5526	0.9756	0.9149	2.0690	1.8335	1.5823	1.3874	1.4446	1.3654	1.0189	0.9768	2.1856	1.9947	1.4121	1.2534	1.5808	1.5022	0.9604	0.9097	1.7946	1.6352	1.3830	1.2673	1.3490	1.2918	1.0043	0.9728
				Wood	2.2367	2.0158	1.5084	1.3131	1.3490	1.2701	0.8673	0.8230	1.9053	1.7045	1.4285	1.2571	1.3122	1.2512	0.9137	0.8821	2.0223	1.8620	1.2584	1.1207	1.3252	1.2614	0.8592	0.8227	1.6173	1.4802	1.2169	1.1092	1.1869	1.1429	0.8843	0.8601
			Hurricane	Other	1.3837	1.1067	0.9468	0.6955	1.0888	1.0090	0.7454	0.6955	1.3181	1.0786	1.1092	0.9282	1.1352	1.0730	0.8540	0.8193	1.1027	0.9093	0.8079	0.6528	1.0470	0.9093	0.6962	0.6528	1.1349	0.9808	0.9833	0.8858	1.0238	0.9787	0.8125	0.7881
				Wood	0.9802	0.7345	0.7184	0.5291	0.6615	0.5903	0.4926	0.4524	1.0733	0.8800	0.9353	0.7976	0.9035	0.8493	0.7240	0.6968	0.7602	0.6043	0.6055	0.4972	0.5690	0.5226	0.4660	0.4403	0.9004	0.7828	0.8144	0.7423	0.7775	0.7438	0.6881	0.6702
		Clips	None	Other	1.8345	1.4895	1.3434	1.0102	1.1377	1.0204	0.7816	0.6996	1.7611	1.4799	1.4517	1.2135	1.2488	1.1584	0.9588	0.9121	1.6275	1.3895	1.1881	0.9861	1.1389	1.0461	0.7983	0.7367	1.5662	1.3803	1.2992	1.1652	1.2005	1.1395	0.9539	0.9214
				Wood	1.6352	1.3611	1.1488	0.8623	0.9923	0.9134	0.6383	0.5832	1.5634	1.3239	1.2751	1.0597	1.1101	1.0433	0.8342	0.7986	1.4177	1.2252	0.9923	0.8085	0.9455	0.8877	0.6377	0.5941	1.3496	1.1829	1.1194	0.9947	1.0074	0.9619	0.8103	0.7837
			Hurricane	Other	1.1101	0.7537	0.9124	0.6399	0.8212	0.7287	0.6009	0.5387	1.2639	1.0031	1.1012	0.9152	1.0223	0.9489	0.8128	0.7738	0.9601	0.7265	0.7992	0.6408	0.7874	0.7178	0.5879	0.5430	1.1123	0.9520	0.9796	0.8778	0.9301	0.8815	0.7902	0.7624
				Wood	0.8311	0.5634	0.7058	0.5111	0.5913	0.5130	0.4817	0.4406	1.0492	0.8496	0.9319	0.7902	0.8886	0.8308	0.7228	0.6946	0.6937	0.5288	0.5999	0.4886	0.5272	0.4756	0.4592	0.4341	0.8908	0.7723	0.8091	0.7308	0.7707	0.7364	0.6875	0.6680
		Wraps	None	Other	1.5851	1.1578	1.2899	0.9127	0.9790	0.8292	0.7590	0.6665	1.6637	1.3419	1.4199	1.1603	1.1949	1.0953	0.9468	0.8970	1.4301	1.1371	1.1457	0.9177	1.0105	0.8976	0.7713	0.7033	1.5031	1.2952	1.2813	1.1337	1.1593	1.0922	0.9431	0.9081
				Wood	1.3459	0.9895	1.0817	0.7491	0.8001	0.7030	0.6040	0.5371	1.4480	1.1631	1.2401	1.0037	1.0334	0.9601	0.8147	0.7751	1.1782	0.9254	0.9502	0.7379	0.7735	0.6989	0.5972	0.5452	1.2673	1.0792	1.1021	0.9638	0.9434	0.8926	0.7905	0.7621
			Hurricane	Other	1.0789	0.7002	0.9081	0.6337	0.7243	0.6136	0.5913	0.5229	1.2643	0.9895	1.0981	0.9100	0.9929	0.9134	0.8094	0.7692	0.9480	0.7042	0.7949	0.6349	0.7005	0.6179	0.5804	0.5328	1.1071	0.9455	0.9771	0.8744	0.9093	0.8571	0.7859	0.7593
				Wood	0.8230	0.5495	0.6989	0.5037	0.5767	0.5012	0.4811	0.4403	1.0446	0.8450	0.9257	0.7831	0.8852	0.8286	0.7209	0.6934	0.6872	0.5170	0.5907	0.4811	0.5192	0.4688	0.4582	0.4313	0.8858	0.7655	0.8057	0.7249	0.7683	0.7333	0.6847	0.6671

Table 4-8. Terrain C Loss Relativities: (FBC Roof Cover) Normalized to Typical House

Terrain C Single Family					Low Roof Slope (<= 5.12)								Other Roof Slope (>=6:12)							
					Two Story non-Tile		One Story non-Tile		Two Story Tile		One Story Tile		Two Story non-Tile		One Story non-Tile		Two Story Tile		One Story Tile	
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip
					No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR	No SWR SWR
FBC	A	Toe Nails	None	Other	2.6600 2.5798	1.6649 1.6250	1.6566 1.6098	0.8639 0.8478	2.2912 2.2336	1.5504 1.5201	1.3735 1.3481	0.8140 0.8060	2.0183 1.9536	1.2884 1.2621	1.4440 1.4047	0.8484 0.8354	1.5866 1.5483	1.1983 1.1804	1.1290 1.1114	0.8001 0.7930
				Wood	2.3623 2.2816	1.4660 1.4230	1.3171 1.2782	0.7382 0.7206	2.0022 1.9437	1.3725 1.3416	1.1708 1.1442	0.7092 0.6999	1.8512 1.7819	1.1315 1.1033	1.1866 1.1488	0.7466 0.7296	1.4155 1.3741	1.0430 1.0248	0.9709 0.9502	0.6983 0.6894
			Hurricane	Other	1.7160 1.6708	0.9459 0.9214	1.0780 1.0507	0.6176 0.6046	1.5978 1.5591	0.9796 0.9576	1.0238 1.0077	0.6281 0.6222	0.9316 0.9056	0.6395 0.6262	0.9134 0.8886	0.5705 0.5613	0.9208 0.9007	0.7321 0.7209	0.7980 0.7856	0.5897 0.5851
				Wood	1.3079 1.2679	0.6838 0.6584	0.6711 0.6606	0.3490 0.3441	1.2840 1.2472	0.7670 0.7457	0.7661 0.7596	0.4743 0.4715	0.6086 0.5854	0.4347 0.4205	0.4254 0.4189	0.3227 0.3199	0.6881 0.6705	0.5594 0.5489	0.5356 0.5306	0.4465 0.4446
		Clips	None	Other	2.3140 2.2645	1.5835 1.5585	1.2837 1.2624	0.7503 0.7454	2.1553 2.1157	1.5275 1.5025	1.2624 1.2485	0.7905 0.7862	1.5350 1.5006	1.1779 1.1637	1.0582 1.0436	0.7423 0.7379	1.4313 1.4063	1.1788 1.1665	1.0306 1.0207	0.7735 0.7707
				Wood	1.9632 1.9124	1.3623 1.3360	1.0461 1.0229	0.6092 0.6027	1.8385 1.7992	1.3438 1.3184	1.0554 1.0421	0.6779 0.6733	1.3181 1.2819	0.9960 0.9824	0.8549 0.8363	0.6108 0.6058	1.2246 1.1993	1.0155 1.0043	0.8549 0.8428	0.6618 0.6587
			Hurricane	Other	1.6284 1.5916	0.9434 0.9199	0.9019 0.8864	0.5251 0.5192	1.5842 1.5489	0.9783 0.9576	0.9623 0.9520	0.6074 0.6043	0.8521 0.8292	0.6371 0.6228	0.6894 0.6782	0.4950 0.4920	0.9137 0.8942	0.7321 0.7206	0.7333 0.7259	0.5761 0.5743
				Wood	1.2766 1.2389	0.6829 0.6572	0.6433 0.6346	0.3438 0.3388	1.2778 1.2432	0.7661 0.7457	0.7608 0.7543	0.4734 0.4697	0.5866 0.5634	0.4310 0.4171	0.3985 0.3936	0.3187 0.3162	0.6872 0.6692	0.5591 0.5486	0.5322 0.5269	0.4452 0.4440
		Wraps	None	Other	2.2469 2.2079	1.5820 1.5585	1.2234 1.2126	0.7503 0.7454	2.1371 2.0993	1.5275 1.5025	1.2485 1.2370	0.7893 0.7840	1.4455 1.4220	1.1773 1.1637	0.9975 0.9889	0.7395 0.7364	1.4143 1.3936	1.1788 1.1662	1.0158 1.0084	0.7735 0.7704
				Wood	1.8886 1.8496	1.3605 1.3360	0.9734 0.9607	0.6092 0.6027	1.8209 1.7831	1.3438 1.3181	1.0347 1.0241	0.6754 0.6696	1.2058 1.1822	0.9960 0.9824	0.7775 0.7670	0.6064 0.6030	1.2030 1.1832	1.0152 1.0034	0.8351 0.8267	0.6618 0.6587
			Hurricane	Other	1.6262 1.5897	0.9434 0.9199	0.8747 0.8651	0.5244 0.5192	1.5842 1.5489	0.9783 0.9576	0.9536 0.9455	0.6074 0.6040	0.8490 0.8261	0.6368 0.6228	0.6479 0.6417	0.4944 0.4920	0.9127 0.8939	0.7321 0.7206	0.7287 0.7228	0.5758 0.5743
				Wood	1.2766 1.2389	0.6829 0.6572	0.6417 0.6334	0.3438 0.3388	1.2775 1.2432	0.7661 0.7457	0.7584 0.7519	0.4734 0.4697	0.5854 0.5613	0.4307 0.4168	0.3979 0.3929	0.3187 0.3162	0.6853 0.6683	0.5591 0.5486	0.5313 0.5269	0.4452 0.4440
	B	Toe Nails	None	Other	2.1343 2.0523	1.3261 1.2825	1.4530 1.4063	0.7995 0.7834	1.6674 1.6092	1.1726 1.1402	1.1037 1.0786	0.7290 0.7209	1.9384 1.8744	1.1593 1.1312	1.4053 1.3663	0.8001 0.7865	1.4480 1.4103	1.0464 1.0294	1.0572 1.0402	0.7351 0.7293
				Wood	1.9681 1.8855	1.2169 1.1726	1.1658 1.1278	0.7088 0.6906	1.5371 1.4783	1.0492 1.0164	0.9861 0.9607	0.6460 0.6368	1.8088 1.7401	1.0266 0.9978	1.1621 1.1253	0.7153 0.6983	1.2970 1.2568	0.8967 0.8784	0.9270 0.9056	0.6340 0.6269
			Hurricane	Other	1.0266 0.9796	0.5857 0.5582	0.8834 0.8564	0.5715 0.5582	0.9050 0.8639	0.7061 0.6832	0.7995 0.7828	0.5739 0.5681	0.8057 0.7825	0.5387 0.5257	0.8057 0.7825	0.5387 0.5257	0.7738 0.7546	0.6624 0.6535	0.7413 0.7302	0.5520 0.5489
				Wood	0.6476 0.6049	0.4140 0.3905	0.4459 0.4353	0.3212 0.3178	0.6900 0.6528	0.5730 0.5551	0.5631 0.5554	0.4514 0.4493	0.4926 0.4752	0.3796 0.3691	0.3855 0.3803	0.3128 0.3106	0.5780 0.5613	0.5220 0.5145	0.4963 0.4935	0.4381 0.4369
		Clips	None	Other	1.4567 1.3948	0.9261 0.8886	0.9013 0.8790	0.5724 0.5659	1.3335 1.2837	1.0071 0.9746	0.8923 0.8769	0.6597 0.6547	1.3020 1.2630	0.8874 0.8666	0.9276 0.9106	0.6139 0.6086	1.1819 1.1528	0.9449 0.9301	0.8871 0.8790	0.6788 0.6757
				Wood	1.3082 1.2485	0.7689 0.7321	0.7831 0.7605	0.4548 0.4486	1.1581 1.1101	0.8574 0.8249	0.7717 0.7568	0.5517 0.5473	1.1337 1.0947	0.7048 0.6853	0.7732 0.7546	0.4728 0.4681	0.9870 0.9588	0.7803 0.7661	0.7203 0.7110	0.5514 0.5489
			Hurricane	Other	0.7215 0.6593	0.5458 0.5111	0.6021 0.5851	0.4090 0.4038	0.8496 0.8041	0.6968 0.6730	0.6736 0.6640	0.5263 0.5226	0.6262 0.6006	0.5288 0.5149	0.5894 0.5786	0.4149 0.4115	0.7447 0.7252	0.6563 0.6457	0.6309 0.6259	0.5248 0.5217
				Wood	0.5080 0.4496	0.4022 0.3769	0.3759 0.3651	0.3082 0.3051	0.6680 0.6290	0.5668 0.5470	0.5473 0.5405	0.4493 0.4471	0.4186 0.3988	0.3710 0.3611	0.3394 0.3348	0.3048 0.3029	0.5644 0.5495	0.5136 0.5040	0.4870 0.4851	0.4366 0.4344
		Wraps	None	Other	1.1578 1.0978	0.8605 0.8171	0.7218 0.7054	0.5433 0.5359	1.2240 1.1723	0.9746 0.9434	0.8317 0.8196	0.6445 0.6395	1.0514 1.0152	0.8270 0.8051	0.7717 0.7599	0.5811 0.5761	1.0962 1.0678	0.9186 0.9035	0.8373 0.8292	0.6646 0.6627
				Wood	0.9644 0.9075	0.6940 0.6522	0.5786 0.5634	0.4118 0.4056	1.0322 0.9817	0.8227 0.7921	0.6906 0.6798	0.5288 0.5248	0.8345 0.7998	0.6454 0.6228	0.5727 0.5622	0.4239 0.4192	0.8861 0.8583	0.7568 0.7404	0.6479 0.6405	0.5278 0.5260
			Hurricane	Other	0.6959 0.6250	0.5405 0.5043	0.4892 0.4749	0.3936 0.3877	0.8453 0.7967	0.6946 0.6699	0.6436 0.6337	0.5213 0.5186	0.6083 0.5780	0.5235 0.5080	0.4876 0.4796	0.4044 0.4010	0.7404 0.7206	0.6516 0.6417	0.6064 0.6006	0.5210 0.5192
				Wood	0.5000 0.4390	0.3970 0.3697	0.3651 0.3530	0.3072 0.3035	0.6643 0.6235	0.5640 0.5433	0.5455 0.5374	0.4493 0.4471	0.4097 0.3877	0.3632 0.3527	0.3345 0.3292	0.3026 0.3004	0.5588 0.5430	0.5084 0.5000	0.4861 0.4830	0.4341 0.4335
	C	Toe Nails	None	Other	2.1272 2.0476	1.3261 1.2825	1.4520 1.4053	0.7995 0.7831	1.6321 1.5764	1.1696 1.1364	1.0873 1.0647	0.7287 0.7206	1.9356 1.8719	1.1569 1.1290	1.4047 1.3651	0.7958 0.7822	1.4449 1.4069	1.0461 1.0266	1.0551 1.0377	0.7351 0.7293
				Wood	1.9681 1.8855	1.2169 1.1726	1.1581 1.1197	0.7085 0.6903	1.5108 1.4561	1.0452 1.0127	0.9802 0.9576	0.6429 0.6343	1.8035 1.7348	1.0260 0.9963	1.1621 1.1253	0.7119 0.6943	1.2964 1.2565	0.8967 0.8784	0.9214 0.9016	0.6340 0.6269
			Hurricane	Other	1.0059 0.9641	0.5811 0.5551	0.8793 0.8537	0.5715 0.5551	0.8614 0.8258	0.7002 0.6785	0.7902 0.7754	0.5730 0.5668	0.8054 0.7819	0.5381 0.5254	0.8054 0.7819	0.5381 0.5254	0.7735 0.7540	0.6621 0.6519	0.7404 0.7302	0.5514 0.5480
				Wood	0.6247 0.5903	0.4124 0.3902	0.4363 0.4285	0.3202 0.3175	0.6597 0.6306	0.5699 0.5511	0.5551 0.5483	0.4511 0.4486	0.4926 0.4740	0.3787 0.3688	0.3846 0.3796	0.3116 0.3100	0.5780 0.5613	0.5220 0.5142	0.4950 0.4935	0.4381 0.4363
		Clips	None	Other	1.4127 1.3537	0.9143 0.8756	0.8830 0.8620	0.5702 0.5634	1.2710 1.2231	0.9910 0.9573	0.8685 0.8543	0.6566 0.6516	1.2986 1.2596	0.8837 0.8629	0.9270 0.9090	0.6139 0.6086	1.1785 1.1501	0.9428 0.9254	0.8871 0.8787	0.6782 0.6748
				Wood	1.2782 1.2209	0.7602 0.7228	0.7738 0.7534	0.4545 0.4483	1.1129 1.0668	0.8397 0.8057	0.7633 0.7485	0.5480 0.5446	1.1290 1.0900	0.7024 0.6829	0.7729 0.7531	0.4728 0.4681	0.9836 0.9564	0.7763 0.7605	0.7203 0.7110	0.5514 0.5470
			Hurricane	Other	0.6584 0.6117	0.5350 0.5009	0.5863 0.5718	0.4081 0.4038	0.7899 0.7509	0.6878 0.6646	0.6569 0.6476	0.5238 0.5210	0.6235 0.5981	0.5263 0.5118	0.5894 0.5783	0.4149 0.4115	0.7444 0.7246	0.6550 0.6451	0.6290 0.6238	0.5232 0.5198
				Wood	0.4641 0.4257	0.3960 0.3725	0.3642 0.3564	0.3072 0.3041	0.6330 0.6027	0.5619 0.5439	0.5377 0.5325	0.4486 0.4471	0.4162 0.3963	0.3710 0.3601	0.3391 0.3338	0.3048 0.3029	0.5644 0.5483	0.5121 0.5034	0.4870 0.4842	0.4366 0.4344
		Wraps	None	Other	1.0783 1.0186	0.8283 0.7757	0.6897 0.6733	0.5390 0.5309	1.1355 1.0845	0.9425 0.9044	0.7964 0.7840	0.6411 0.6368	1.0455 1.0090	0.8181 0.7936	0.7701 0.7571	0.5795 0.5746	1.0891 1.0616	0.9084 0.8917	0.8351 0.8274	0.6640 0.6618
				Wood	0.9044 0.8490	0.6624 0.6126	0.5619 0.5486	0.4072 0.4010	0.9604 0.9112	0.7915 0.7550	0.6674 0.6566	0.5254 0.5220	0.8283 0.7936	0.6352 0.6117	0.5718 0.5597	0.4199 0.4152	0.8800 0.8527	0.7450 0.7290	0.6457 0.6380	0.5263 0.5238
			Hurricane	Other	0.6170 0.5597	0.5300 0.4947	0.4678 0.4564	0.3908 0.3849	0.7760 0.7367	0.6844 0.6590	0.6210 0.6120	0.5192 0.5152	0.6033 0.5755	0.5213 0.5074	0.4861 0.4777	0.4038 0.4001	0.7370 0.7175	0.6504 0.6392	0.6043 0.5978	0.5189 0.5170
				Wood	0.4483 0.4078	0.3886 0.3645	0.3515 0.3444	0.3066 0.3035	0.6272 0.5959	0.5575 0.5371	0.5362 0.5303	0.4480 0.4449	0.4066 0.3868	0.3620 0.3518	0.3329 0.3283	0.3020 0.3001	0.5579 0.5430	0.5074 0.4966	0.4861 0.4817	0.4338 0.4325

The weakest house in Terrain B has losses that are about 3.5 times the typical house, while the weakest house in Terrain C has losses about 3.4 times the typical house. The overall ranges of relativity (max divided by min) are 7.5 for Terrain B and 10.3 for Terrain C. These ranges include a judgment-based compression, as was done in 2002. Prior to compression, the modeled results for 2% deductible had ranges of 11.3 for B and 28.2 for C. The judgment-based compression factors [K in Eq. C-1, ARA (2002a)] used were 0.04 for Terrain B and 0.06 for Terrain C. These factors are slightly less than the K factors used in 2002 (0.05 for B and 0.07 for C), reflecting the fact that we have more field data, insurance data, and improved models. The results were compressed due to non-modeled features and potential modeling errors.

Since new mitigation features have been introduced in this study, one would expect the range of relativities to increase, reflecting the fact that each feature has a weak/strong complement. However, the overall range did not increase in proportion to the new range of building strengths. The ranges did not increase proportionally because of updates to the loss modeling, which reflected updates for non-building envelope losses. As discussed in Section 3.3, we spent a great deal of effort looking for losses not related to the dwelling envelope strength. Such losses tend to compress the loss relativities since they are generally independent of the wind mitigation features. For example, if non-building envelope losses totally dominate the dwelling envelope losses, then the loss relativities would be the same for all buildings in the matrix and there would be no basis for wind mitigation rate differentials. We found that attached and detached structure losses significantly influence the compression of the relativities. Hence the portion of the wind premium associated with these non-dwelling structures should not be included when computing wind mitigation rate differentials.

Updates to the loss adjustment models based on detailed claim folder review included treatments for exterior accessories, water leakage, tree removal and tree debris removal, and roof cover loss adjustment. Exterior accessories are components of the building that are located on the exterior of the building but are not considered part of the building envelope (such as exterior lights, electrical drip lines, air conditioning units, exterior trim, gutters, etc.). Losses to these components are independent of the wind mitigation features in the above tables and hence tend to compress the differences in loss for mitigated and unmitigated buildings. The loss model was updated by developing a model of exterior accessory losses from analysis of the claim folder level data. Similarly, water leakage, tree removal, and roof cover loss adjustments were treated explicitly in the updated loss modeling. Based on this research and the updated modeling approach, the results in the loss relativity tables reflect these non-building, strength-related losses for all buildings. As a result, the loss costs are compressed (when compared to the 2002 range increased by the new features that would otherwise significantly widen that range).[26]

Attached and Detached Structures. The results do not include the effects of attached and detached (exterior) structures, such as pool/patio screen enclosure, carports, fences, gazebos, utility sheds, decks, patios, driveways, swimming pools, etc. As mentioned previously, the relativities are strictly applicable only to that portion of the insurance premium that covers the dwelling, dwelling contents, and additional living expenses resulting from damage to the dwelling. Hence, insurance companies must determine the appropriate fraction of the wind premium that is applicable to the wind mitigation rate differentials. An example analysis of the effects of including exterior structures on the computed loss relativities is given in Section 6.

Terrain. Within the scope of this study, we provide separate loss relativity tables for each of two terrains, B and C. The Terrain B results have been developed using surface roughness that the model building is surrounded by one story buildings for some distance in all directions. The Terrain C results assume that the building is located in open terrain. The relative difference in loss costs is wider for Terrain C vs. Terrain B since a Terrain C house experiences higher loads more often that the same house

[26] However, as noted previously, the losses do not include a separate, explicit model for tree-fall damage to houses. Due to schedule issues, this research was not complete, nor was treed terrain considered in the terrain groups.

in Terrain B. The differences in loss costs for the same building in Terrain C vs. Terrain B are significant. Each terrain table is normalized to itself, which means that one cannot quantify the differences in loss cost for the different terrains based on the loss relativity results in this report. This approach for terrain is identical to what was done in the 2002 studies.

Knowledge of terrain (surface roughness in the vicinity of the building) is critical to accurate estimation of loss costs for a building. For the same building in the same territory, the differences in loss costs from a coastal location to a heavily treed location could be a factor of 10. Surface roughness effects can vary significantly over distances as small as ¼ to ½ mile. Since losses are proportional to the cube or greater power of the windspeed experienced by the building, knowledge of the terrain the building is essential to understanding loss mitigation. Hence, surface roughness is a key building design parameter and also a powerful discriminator of hurricane losses. We note that the modeled loss cost differences are significant. The insurance data analysis also suggested a large difference in losses (see Sections 3.3.7 and 3.3.10) in a very simplified analysis, which showed a factor of 2 difference in Terrain B vs. Terrain C.

Terrain is not a distinct rating factor currently used by insurance companies. That is, most insurers do not have different base rates based on terrain within the same rating territory. Another challenge is that there is a difference in actual terrain and simplified building code terrain. The mitigation inspections in the past have used a simplified building code terrain, which is based on the 2001 FBC definitions of terrain. Using these 2001 FBC definitions, inland locations are Terrain B and coastal locations are Terrain C. Actual terrains include a continuum of surface roughness and reflect the fact that the surface roughness at a site is generally different over the full range of possible wind directions.

Modern technology allows terrain to be determined on a building-by-building basis, using street address and geocoding. This is the preferred approach because terrain has such a large impact on what the base rate should be. Within each rating territory, there should be distinct rates for up to 4 terrains (Coastal, Open, Suburban, Treed). Since the rate differences are significant across each terrain and the relative importance of building mitigation features varies with terrain, the determination of terrain is the first step to determining the applicable loss relativity table.[27]

There are many possible ways for an insurance company to deal with terrain. The most common approach in the past has been to use "building code terrain," which is included on the inspection form to determine which loss relativity table to apply to the house. Since terrain has such a strong influence on the loads on the building and on the expected losses, insurers should consider a more systematic approach in rating all buildings by both location and terrain.

Discussion of New Features. The following paragraphs discuss the effect of the new building features (soffits, tiles, number of stories and roof slope) on the loss relativities.

The relativities indicate that the loss costs for a two-story house situated in Exposure B are about double those of a one-story house. Most of this difference is directly attributable to the difference in the heights of the buildings. The mean roof heights of the one and two-story 4:12 gable roof houses are 11½ and 19½ ft respectively. The ratio of the velocity pressure at the mean roof height in exposure B is 1.62, indicating the two-story buildings will experience wind pressures about 60% higher than a one-story house for the same hurricane.

The effect of roof tiles varies with other construction characteristics of the buildings. In the case of houses with toe-nail roof-to-wall connections, where a predominant failure mode includes the failure of the entire roof, the extra weight of roof tiles acts to help keep the roof on, thus reducing losses. In cases where whole roof failures are infrequent (i.e., wrap roof-to-wall connections), the relativities for buildings

[27] This approach is best applied with additional loss relativity tables for Coastal and Treed terrains. We recommend that this work be completed and additional terrains be included in wind mitigation rate differentials.

with tiles increases (compared to shingles) because the replacement cost of tiles are generally higher than that of shingles. The tile relativities were found to be sensitive to the damage threshold that triggered the replacement of all the tiles on a roof as compared to simply repairing the damaged area. Obtaining a better understanding of the repair or replace threshold for tile roof houses was a focus area of the claim folder study.

Roof slope is an important factor in roof design. Recent wind tunnel tests, discussed in Section 3.6.1.2, provide data on wind pressure coefficients for different slope roofs. The pressure loads are reduced for steeper roof slopes. The main effect of steeper roof slopes is to reduce losses over the lower slope houses, which results from the improved aerodynamics of the steeper roofs. For the same windspeeds, the 7:12 roofs experience lower uplift forces than the 4:12 slope. However, the 7:12 roof has a higher mean roof height and experiences slightly higher windspeeds on average. The average effect is about an 11% reduction across all houses for both Terrain B and Terrain C. The maximum % reduction is about 50% for both terrains. About 6% and 8% of the Terrain B and C houses, respectively, have slightly higher relativities for 7:12 than for 4:12 roof slopes. However, the relative differences in these cases are small, averaging about a 3% difference. A final comment on roof slope is that steeper roofs generally are less likely to leak and also last longer than roofs with less pitch. Water runs off a steep roof quickly (promoting faster drying) and does not back up as readily during high winds.

The introduction of soffits as a failure mode, allowing internal pressurization of the building and allowing water to enter the attic space has the effect of increasing losses by an average of about 25%. We note that most houses have wood soffits that would qualify for the "Wood" soffit feature. Houses with weak soffits (such as vinyl), which are prone to both positive and negative pressure failures, will experience higher losses. If the building envelope is strong in all areas except the soffits, then weak soffits are the "weak link" in the building envelope; the relativities differ by as much as 50% in this case.

We note that the effects of tiles and number of stories on losses are generally consistent with that observed from the insurance data analysis described previously in Section 3.2.

4.2.4.4 Loss Relativities Normalized by Weakest House

The loss relativities can be normalized by any cell in the tables and retain the linear relationship between loss costs and loss relativities. Table 4-9 through Table 4-12 present the relativities where the weakest house has a loss relativity of 1.0. For both Terrain B and Terrain C, the weakest house has the following features:

1. Number of stories: 2
2. Roof Slope: 4:12
3. Roof cover type: Non-tile
4. Roof cover strength: Non FBC
5. Roof wall connections: Toe nail
6. Roof deck strength: A (6d at 6-12)
7. Roof shape: Gable
8. Soffits: Other
9. Opening protection: None
10. Secondary water resistance: None

Table 4-9. Terrain B Loss Relativities (Non-FBC Roof Cover) Normalized to Weakest House

Weakest

Terrain B Single Family					Low Roof Slope (<= 5.12)																Other Roof Slope (>=6:12)											
					Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile				Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile			
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip	
					No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
Non-FBC	A	Toe Nails	None	Other	1.0000	0.8356	0.5835	0.4853	0.5051	0.4732	0.2696	0.2563	0.9973	0.8857	0.6536	0.5904	0.5439	0.5227	0.3435	0.3356	0.6233	0.5259	0.4480	0.3837	0.4050	0.3833	0.2654	0.2544	0.6517	0.5834	0.5282	0.4863	0.4363	0.4232	0.3356	0.3292
				Wood	0.9154	0.7607	0.5306	0.4398	0.4847	0.4557	0.2564	0.2443	0.9222	0.8162	0.6094	0.5510	0.5235	0.5035	0.3320	0.3246	0.5572	0.4681	0.4028	0.3429	0.3828	0.3628	0.2494	0.2399	0.5921	0.5291	0.4896	0.4503	0.4099	0.3984	0.3208	0.3147
			Hurricane	Other	0.8622	0.6885	0.4907	0.3936	0.3951	0.3642	0.2390	0.2274	0.8989	0.7854	0.5757	0.5141	0.4895	0.4701	0.3213	0.3145	0.4882	0.3919	0.3644	0.3033	0.3060	0.2871	0.2287	0.2203	0.5606	0.4958	0.4583	0.4196	0.3849	0.3725	0.3085	0.3030
				Wood	0.7928	0.6288	0.4530	0.3613	0.3681	0.3378	0.2285	0.2174	0.8447	0.7379	0.5445	0.4874	0.4746	0.4560	0.3144	0.3084	0.4346	0.3460	0.3331	0.2781	0.2784	0.2607	0.2178	0.2107	0.5198	0.4600	0.4327	0.3965	0.3702	0.3592	0.3012	0.2964
		Clips	None	Other	0.9641	0.7874	0.5820	0.4818	0.4416	0.4068	0.2647	0.2512	0.9900	0.8776	0.6530	0.5896	0.5373	0.5163	0.3435	0.3353	0.5768	0.4714	0.4451	0.3794	0.3459	0.3223	0.2590	0.2480	0.6448	0.5764	0.5273	0.4854	0.4298	0.4152	0.3353	0.3288
				Wood	0.8719	0.7043	0.5293	0.4348	0.4166	0.3849	0.2496	0.2375	0.9135	0.8054	0.6089	0.5496	0.5142	0.4947	0.3320	0.3246	0.5051	0.4108	0.3994	0.3382	0.3143	0.2940	0.2413	0.2314	0.5857	0.5214	0.4877	0.4486	0.4003	0.3878	0.3202	0.3141
			Hurricane	Other	0.8553	0.6784	0.4903	0.3933	0.3767	0.3439	0.2346	0.2232	0.8987	0.7848	0.5755	0.5140	0.4879	0.4686	0.3202	0.3135	0.4782	0.3785	0.3640	0.3032	0.2880	0.2664	0.2254	0.2167	0.5698	0.4949	0.4583	0.4196	0.3833	0.3706	0.3082	0.3027
				Wood	0.7903	0.6226	0.4529	0.3613	0.3572	0.3271	0.2263	0.2161	0.8447	0.7378	0.5445	0.4874	0.4739	0.4550	0.3140	0.3080	0.4279	0.3387	0.3322	0.2777	0.2693	0.2499	0.2158	0.2083	0.5184	0.4590	0.4327	0.3965	0.3688	0.3580	0.3009	0.2964
		Wraps	None	Other	0.9593	0.7848	0.5820	0.4818	0.4382	0.4045	0.2647	0.2512	0.9893	0.8769	0.6530	0.5896	0.5370	0.5163	0.3435	0.3353	0.5744	0.4682	0.4451	0.3794	0.3441	0.3194	0.2590	0.2480	0.6445	0.5752	0.5273	0.4854	0.4295	0.4149	0.3353	0.3288
				Wood	0.8701	0.7043	0.5293	0.4348	0.4119	0.3822	0.2496	0.2375	0.9126	0.8039	0.6088	0.5496	0.5137	0.4947	0.3320	0.3246	0.5036	0.4074	0.3994	0.3382	0.3110	0.2889	0.2413	0.2314	0.5857	0.5193	0.4877	0.4486	0.4003	0.3878	0.3202	0.3141
			Hurricane	Other	0.8553	0.6781	0.4903	0.3933	0.3756	0.3429	0.2346	0.2231	0.8981	0.7847	0.5755	0.5140	0.4879	0.4679	0.3202	0.3135	0.4782	0.3782	0.3640	0.3032	0.2862	0.2647	0.2253	0.2166	0.5698	0.4948	0.4583	0.4196	0.3833	0.3700	0.3082	0.3027
				Wood	0.7903	0.6226	0.4529	0.3613	0.3571	0.3271	0.2263	0.2159	0.8447	0.7378	0.5445	0.4874	0.4739	0.4548	0.3140	0.3080	0.4279	0.3387	0.3322	0.2777	0.2682	0.2498	0.2158	0.2083	0.5184	0.4590	0.4327	0.3965	0.3688	0.3577	0.3009	0.2964
	B	Toe Nails	None	Other	0.6730	0.5568	0.4573	0.3702	0.4272	0.4051	0.2538	0.2434	0.6958	0.5983	0.5473	0.4867	0.4619	0.4449	0.3308	0.3241	0.5695	0.4844	0.4082	0.3489	0.3912	0.3720	0.2555	0.2455	0.5939	0.5282	0.4930	0.4525	0.4160	0.4029	0.3281	0.3222
				Wood	0.6232	0.5135	0.4211	0.3438	0.4190	0.3986	0.2414	0.2327	0.6527	0.5612	0.5168	0.4607	0.4482	0.4340	0.3199	0.3139	0.5115	0.4351	0.3695	0.3159	0.3724	0.3549	0.2408	0.2329	0.5435	0.4832	0.4573	0.4207	0.3923	0.3805	0.3129	0.3078
			Hurricane	Other	0.5213	0.4060	0.3764	0.2974	0.3228	0.3031	0.2295	0.2212	0.6044	0.5117	0.4888	0.4339	0.4256	0.4098	0.3128	0.3075	0.4281	0.3480	0.3294	0.2783	0.2936	0.2786	0.2241	0.2162	0.5043	0.4448	0.4334	0.3985	0.3708	0.3598	0.3025	0.2978
				Wood	0.4717	0.3605	0.3531	0.2809	0.2973	0.2784	0.2195	0.2122	0.5740	0.4885	0.4710	0.4207	0.4164	0.4006	0.3082	0.3031	0.3797	0.3070	0.3050	0.2609	0.2666	0.2514	0.2144	0.2076	0.4703	0.4180	0.4138	0.3823	0.3585	0.3481	0.2967	0.2929
		Clips	None	Other	0.5707	0.4257	0.4345	0.3375	0.3257	0.2990	0.2423	0.2307	0.6687	0.5636	0.5428	0.4764	0.4434	0.4256	0.3295	0.3228	0.4971	0.3972	0.3956	0.3311	0.3145	0.2919	0.2463	0.2350	0.5764	0.5058	0.4896	0.4477	0.4031	0.3889	0.3266	0.3199
				Wood	0.5175	0.3882	0.3979	0.3097	0.3091	0.2863	0.2288	0.2194	0.6222	0.5268	0.5124	0.4495	0.4267	0.4117	0.3182	0.3126	0.4373	0.3498	0.3540	0.2960	0.2858	0.2669	0.2286	0.2186	0.5231	0.4597	0.4532	0.4138	0.3752	0.3642	0.3108	0.3050
			Hurricane	Other	0.4760	0.3400	0.3709	0.2892	0.2872	0.2653	0.2209	0.2118	0.5968	0.5013	0.4881	0.4329	0.4175	0.4005	0.3121	0.3055	0.4013	0.3115	0.3287	0.2764	0.2659	0.2482	0.2176	0.2100	0.4997	0.4399	0.4334	0.3985	0.3642	0.3524	0.3008	0.2964
				Wood	0.4401	0.3173	0.3490	0.2765	0.2783	0.2581	0.2164	0.2080	0.5683	0.4823	0.4708	0.4201	0.4100	0.3958	0.3079	0.3030	0.3615	0.2845	0.3048	0.2597	0.2520	0.2357	0.2117	0.2052	0.4669	0.4150	0.4138	0.3823	0.3547	0.3449	0.2953	0.2920
		Wraps	None	Other	0.5531	0.4000	0.4345	0.3351	0.3147	0.2854	0.2422	0.2301	0.6640	0.5571	0.5415	0.4747	0.4417	0.4226	0.3293	0.3226	0.4844	0.3772	0.3955	0.3294	0.3042	0.2799	0.2457	0.2344	0.5726	0.5004	0.4895	0.4477	0.4012	0.3863	0.3266	0.3199
				Wood	0.4984	0.3599	0.3979	0.3070	0.2942	0.2698	0.2286	0.2187	0.6168	0.5201	0.5109	0.4477	0.4248	0.4080	0.3176	0.3122	0.4227	0.3274	0.3530	0.2930	0.2716	0.2514	0.2273	0.2180	0.5183	0.4527	0.4532	0.4138	0.3732	0.3610	0.3108	0.3050
			Hurricane	Other	0.4728	0.3332	0.3709	0.2892	0.2839	0.2594	0.2209	0.2113	0.5968	0.4990	0.4874	0.4326	0.4159	0.3993	0.3116	0.3054	0.3990	0.3083	0.3285	0.2760	0.2612	0.2424	0.2172	0.2095	0.4994	0.4392	0.4333	0.3981	0.3641	0.3523	0.3008	0.2964
				Wood	0.4370	0.3122	0.3490	0.2763	0.2765	0.2541	0.2161	0.2080	0.5683	0.4791	0.4703	0.4199	0.4094	0.3945	0.3079	0.3029	0.3592	0.2824	0.3045	0.2596	0.2497	0.2339	0.2109	0.2049	0.4667	0.4138	0.4138	0.3823	0.3546	0.3449	0.2953	0.2920
	C	Toe Nails	None	Other	0.6627	0.5530	0.4572	0.3702	0.4244	0.4034	0.2536	0.2434	0.6753	0.5875	0.5473	0.4860	0.4577	0.4422	0.3308	0.3239	0.5679	0.4834	0.4080	0.3482	0.3907	0.3717	0.2555	0.2455	0.5932	0.5278	0.4926	0.4525	0.4160	0.4025	0.3281	0.3222
				Wood	0.6114	0.5083	0.4211	0.3438	0.4154	0.3961	0.2412	0.2327	0.6361	0.5656	0.5168	0.4605	0.4463	0.4313	0.3199	0.3137	0.5109	0.4343	0.3694	0.3152	0.3715	0.3543	0.2408	0.2329	0.5425	0.4832	0.4565	0.4205	0.3922	0.3805	0.3129	0.3078
			Hurricane	Other	0.5078	0.4016	0.3752	0.2971	0.3208	0.3029	0.2290	0.2206	0.5845	0.5027	0.4876	0.4339	0.4214	0.4070	0.3128	0.3075	0.4271	0.3480	0.3294	0.2783	0.2933	0.2783	0.2238	0.2162	0.5029	0.4443	0.4330	0.3985	0.3708	0.3598	0.3022	0.2978
				Wood	0.4582	0.3561	0.3506	0.2791	0.2949	0.2775	0.2195	0.2116	0.5660	0.4819	0.4696	0.4207	0.4119	0.3986	0.3082	0.3031	0.3780	0.3062	0.3050	0.2609	0.2658	0.2508	0.2141	0.2076	0.4695	0.4171	0.4135	0.3818	0.3585	0.3480	0.2966	0.2929
		Clips	None	Other	0.5440	0.4099	0.4331	0.3352	0.3208	0.2966	0.2420	0.2301	0.6446	0.5468	0.5398	0.4733	0.4383	0.4215	0.3284	0.3212	0.4964	0.3950	0.3956	0.3311	0.3145	0.2919	0.2463	0.2350	0.5750	0.5049	0.4895	0.4473	0.4031	0.3889	0.3266	0.3199
				Wood	0.4975	0.3764	0.3961	0.3077	0.3047	0.2844	0.2285	0.2187	0.6030	0.5127	0.5083	0.4461	0.4213	0.4067	0.3167	0.3101	0.4373	0.3485	0.3540	0.2960	0.2852	0.2669	0.2284	0.2186	0.5231	0.4582	0.4532	0.4138	0.3752	0.3640	0.3108	0.3050
			Hurricane	Other	0.4499	0.3294	0.3696	0.2875	0.2852	0.2642	0.2209	0.2118	0.5737	0.4878	0.4868	0.4320	0.4143	0.3989	0.3117	0.3055	0.3989	0.3109	0.3279	0.2764	0.2659	0.2482	0.2175	0.2099	0.4984	0.4384	0.4317	0.3979	0.3642	0.3524	0.3008	0.2964
				Wood	0.4180	0.3091	0.3481	0.2754	0.2762	0.2567	0.2162	0.2080	0.5502	0.4720	0.4691	0.4200	0.4091	0.3957	0.3079	0.3024	0.3587	0.2829	0.3040	0.2597	0.2520	0.2357	0.2112	0.2052	0.4669	0.4133	0.4127	0.3817	0.3547	0.3449	0.2963	0.2920
		Wraps	None	Other	0.5224	0.3803	0.4296	0.3295	0.3082	0.2815	0.2417	0.2298	0.6375	0.5362	0.5389	0.4713	0.4367	0.4182	0.3284	0.3211	0.4831	0.3757	0.3938	0.3283	0.3038	0.2799	0.2457	0.2343	0.5718	0.4994	0.4882	0.4466	0.4010	0.3863	0.3266	0.3199
				Wood	0.4709	0.3464	0.3925	0.3020	0.2895	0.2664	0.2278	0.2184	0.5950	0.5022	0.5070	0.4447	0.4202	0.4038	0.3167	0.3100	0.4213	0.3252	0.3530	0.2930	0.2709	0.2514	0.2270	0.2177	0.5177	0.4514	0.4512	0.4138	0.3720	0.3601	0.3108	0.3050
			Hurricane	Other	0.4451	0.3214	0.3689	0.2869	0.2786	0.2567	0.2204	0.2113	0.5735	0.4860	0.4859	0.4313	0.4119	0.3969	0.3116	0.3053	0.3968	0.3069	0.3276	0.2760	0.2605	0.2417	0.2171	0.2092	0.4980	0.4368	0.4316	0.3979	0.3640	0.3521	0.3008	0.2962
				Wood	0.4146	0.3056	0.3475	0.2751	0.2727	0.2522	0.2161	0.2080	0.5502	0.4716	0.4682	0.4186	0.4068	0.3936	0.3079	0.3024	0.3577	0.2812	0.3034	0.2595	0.2492	0.2331	0.2109	0.2048	0.4654	0.4114	0.4127	0.3817	0.3542	0.3446	0.2953	0.2917

Table 4-10. Terrain B Loss Relativities (FBC Roof Cover) Normalized to Weakest House

Terrain B Single Family					Low Roof Slope (<= 5.12)																Other Roof Slope (>=6.12)											
					Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile				Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile			
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip	
					No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
FBC	A	Toe Nails	None	Other	0.7283	0.7124	0.3886	0.3818	0.3788	0.3716	0.1853	0.1842	0.6898	0.6784	0.4284	0.4223	0.3664	0.3633	0.2281	0.2275	0.4451	0.4348	0.3044	0.3004	0.3065	0.3014	0.1864	0.1857	0.4427	0.4370	0.3552	0.3516	0.2980	0.2957	0.2275	0.2259
				Wood	0.6548	0.6397	0.3450	0.3381	0.3634	0.3554	0.1731	0.1719	0.6235	0.6126	0.3922	0.3865	0.3493	0.3458	0.2169	0.2165	0.3879	0.3766	0.2639	0.2601	0.2886	0.2825	0.1724	0.1711	0.3925	0.3870	0.3202	0.3173	0.2749	0.2732	0.2142	0.2128
			Hurricane	Other	0.5755	0.5642	0.2968	0.2907	0.2659	0.2631	0.1525	0.1514	0.5875	0.5765	0.3571	0.3520	0.3128	0.3117	0.2072	0.2066	0.3068	0.2986	0.2219	0.2182	0.2040	0.2020	0.1484	0.1481	0.3560	0.3500	0.2910	0.2870	0.2503	0.2488	0.2015	0.2015
				Wood	0.5167	0.5059	0.2671	0.2606	0.2374	0.2354	0.1429	0.1418	0.5433	0.5325	0.3334	0.3278	0.2993	0.2985	0.2010	0.2006	0.2591	0.2512	0.1966	0.1928	0.1759	0.1746	0.1384	0.1375	0.3223	0.3163	0.2706	0.2668	0.2361	0.2353	0.1955	0.1955
		Clips	None	Other	0.6719	0.6613	0.3838	0.3784	0.3060	0.3044	0.1789	0.1782	0.6765	0.6657	0.4278	0.4218	0.3557	0.3546	0.2270	0.2261	0.3848	0.3774	0.2988	0.2953	0.2411	0.2392	0.1800	0.1792	0.4321	0.4257	0.3540	0.3511	0.2883	0.2869	0.2259	0.2258
				Wood	0.5929	0.5821	0.3402	0.3348	0.2839	0.2823	0.1648	0.1645	0.6093	0.5989	0.3913	0.3859	0.3360	0.3349	0.2161	0.2154	0.3240	0.3170	0.2684	0.2650	0.2126	0.2105	0.1638	0.1633	0.3802	0.3732	0.3199	0.3171	0.2633	0.2618	0.2125	0.2125
			Hurricane	Other	0.5605	0.5496	0.2961	0.2904	0.2431	0.2412	0.1483	0.1473	0.5871	0.5761	0.3570	0.3518	0.3094	0.3086	0.2062	0.2062	0.2918	0.2842	0.2216	0.2174	0.1818	0.1808	0.1442	0.1441	0.3554	0.3492	0.2908	0.2868	0.2458	0.2450	0.2013	0.2013
				Wood	0.5084	0.4970	0.2657	0.2598	0.2261	0.2251	0.1414	0.1404	0.5428	0.5323	0.3333	0.3277	0.2972	0.2962	0.2005	0.2005	0.2511	0.2438	0.1966	0.1920	0.1660	0.1653	0.1361	0.1357	0.3223	0.3163	0.2705	0.2668	0.2346	0.2340	0.1954	0.1953
		Wraps	None	Other	0.6674	0.6560	0.3838	0.3782	0.3015	0.3003	0.1787	0.1780	0.6765	0.6654	0.4278	0.4218	0.3548	0.3539	0.2270	0.2261	0.3799	0.3727	0.2985	0.2952	0.2356	0.2345	0.1798	0.1792	0.4313	0.4254	0.3540	0.3511	0.2880	0.2869	0.2259	0.2258
				Wood	0.5878	0.5772	0.3399	0.3343	0.2782	0.2772	0.1645	0.1642	0.6091	0.5984	0.3913	0.3859	0.3348	0.3343	0.2161	0.2154	0.3183	0.3111	0.2578	0.2547	0.2062	0.2050	0.1634	0.1633	0.3792	0.3732	0.3199	0.3170	0.2630	0.2618	0.2125	0.2125
			Hurricane	Other	0.5583	0.5480	0.2960	0.2904	0.2416	0.2399	0.1483	0.1473	0.5867	0.5757	0.3570	0.3518	0.3094	0.3082	0.2062	0.2062	0.2915	0.2842	0.2216	0.2174	0.1798	0.1791	0.1441	0.1441	0.3553	0.3491	0.2908	0.2868	0.2454	0.2450	0.2013	0.2013
				Wood	0.5083	0.4970	0.2657	0.2598	0.2256	0.2245	0.1414	0.1404	0.5424	0.5323	0.3333	0.3277	0.2972	0.2959	0.2005	0.2005	0.2506	0.2435	0.1966	0.1920	0.1647	0.1640	0.1361	0.1357	0.3223	0.3163	0.2705	0.2668	0.2343	0.2337	0.1954	0.1953
	B	Toe Nails	None	Other	0.4739	0.4585	0.2889	0.2816	0.3188	0.3117	0.1734	0.1722	0.4486	0.4355	0.3495	0.3430	0.2969	0.2943	0.2175	0.2168	0.4064	0.3969	0.2747	0.2710	0.2971	0.2923	0.1791	0.1779	0.4016	0.3943	0.3285	0.3251	0.2834	0.2814	0.2208	0.2206
				Wood	0.4295	0.4141	0.2628	0.2560	0.3106	0.3031	0.1625	0.1612	0.4128	0.4000	0.3251	0.3188	0.2861	0.2830	0.2080	0.2070	0.3557	0.3464	0.2406	0.2365	0.2782	0.2727	0.1657	0.1645	0.3588	0.3507	0.2979	0.2941	0.2637	0.2610	0.2085	0.2081
			Hurricane	Other	0.3191	0.3069	0.2118	0.2051	0.2093	0.2065	0.1473	0.1464	0.3626	0.3512	0.2974	0.2911	0.2605	0.2578	0.2019	0.2019	0.2670	0.2608	0.1997	0.1958	0.1976	0.1953	0.1457	0.1448	0.3185	0.3125	0.2757	0.2725	0.2403	0.2390	0.1983	0.1980
				Wood	0.2731	0.2609	0.1950	0.1883	0.1825	0.1806	0.1382	0.1378	0.3388	0.3283	0.2842	0.2788	0.2518	0.2496	0.1975	0.1975	0.2235	0.2183	0.1811	0.1778	0.1694	0.1677	0.1361	0.1354	0.2920	0.2862	0.2602	0.2578	0.2287	0.2280	0.1941	0.1935
		Clips	None	Other	0.3426	0.3264	0.2579	0.2485	0.2072	0.2046	0.1604	0.1596	0.4170	0.4037	0.3400	0.3329	0.2749	0.2731	0.2155	0.2148	0.3200	0.3108	0.2570	0.2516	0.2134	0.2118	0.1678	0.1673	0.3802	0.3715	0.3236	0.3203	0.2673	0.2662	0.2185	0.2185
				Wood	0.3044	0.2889	0.2297	0.2201	0.1938	0.1916	0.1488	0.1478	0.3804	0.3683	0.3130	0.3059	0.2608	0.2598	0.2054	0.2054	0.2716	0.2629	0.2208	0.2159	0.1869	0.1854	0.1515	0.1512	0.3340	0.3264	0.2918	0.2887	0.2435	0.2423	0.2052	0.2052
			Hurricane	Other	0.2578	0.2409	0.2055	0.1977	0.1717	0.1697	0.1371	0.1369	0.3528	0.3404	0.2958	0.2894	0.2512	0.2495	0.1996	0.1995	0.2318	0.2234	0.1979	0.1941	0.1663	0.1649	0.1378	0.1373	0.3139	0.3073	0.2746	0.2715	0.2323	0.2316	0.1969	0.1966
				Wood	0.2337	0.2182	0.1910	0.1845	0.1640	0.1616	0.1335	0.1333	0.3321	0.3221	0.2829	0.2769	0.2459	0.2441	0.1967	0.1966	0.2027	0.1953	0.1801	0.1767	0.1539	0.1528	0.1332	0.1326	0.2886	0.2830	0.2592	0.2568	0.2249	0.2246	0.1936	0.1931
		Wraps	None	Other	0.3186	0.3012	0.2559	0.2453	0.1937	0.1911	0.1599	0.1590	0.4103	0.3960	0.3389	0.3313	0.2720	0.2705	0.2155	0.2148	0.3027	0.2913	0.2554	0.2503	0.2021	0.1998	0.1674	0.1668	0.3752	0.3663	0.3231	0.3191	0.2650	0.2637	0.2183	0.2182
				Wood	0.2788	0.2615	0.2267	0.2165	0.1775	0.1754	0.1480	0.1470	0.3727	0.3593	0.3125	0.3054	0.2572	0.2565	0.2054	0.2054	0.2498	0.2393	0.2192	0.2137	0.1735	0.1708	0.1506	0.1501	0.3279	0.3195	0.2910	0.2879	0.2397	0.2388	0.2048	0.2048
			Hurricane	Other	0.2539	0.2343	0.2050	0.1971	0.1654	0.1630	0.1365	0.1363	0.3518	0.3395	0.2953	0.2890	0.2496	0.2479	0.1995	0.1992	0.2290	0.2198	0.1974	0.1934	0.1603	0.1590	0.1376	0.1372	0.3122	0.3061	0.2744	0.2715	0.2309	0.2304	0.1968	0.1966
				Wood	0.2312	0.2137	0.1908	0.1843	0.1598	0.1578	0.1333	0.1333	0.3321	0.3216	0.2825	0.2765	0.2450	0.2438	0.1967	0.1966	0.2002	0.1925	0.1794	0.1763	0.1515	0.1507	0.1331	0.1326	0.2879	0.2821	0.2589	0.2568	0.2248	0.2240	0.1935	0.1931
	C	Toe Nails	None	Other	0.4687	0.4537	0.2888	0.2814	0.3173	0.3103	0.1734	0.1722	0.4397	0.4287	0.3489	0.3419	0.2946	0.2920	0.2175	0.2168	0.4064	0.3969	0.2742	0.2704	0.2971	0.2919	0.1791	0.1779	0.4014	0.3941	0.3278	0.3243	0.2831	0.2814	0.2208	0.2202
				Wood	0.4252	0.4101	0.2628	0.2560	0.3106	0.3031	0.1625	0.1612	0.4072	0.3959	0.3248	0.3172	0.2852	0.2820	0.2080	0.2070	0.3557	0.3464	0.2399	0.2362	0.2782	0.2727	0.1657	0.1645	0.3572	0.3500	0.2965	0.2926	0.2635	0.2610	0.2085	0.2081
			Hurricane	Other	0.3109	0.3005	0.2115	0.2051	0.2093	0.2064	0.1473	0.1464	0.3527	0.3437	0.2958	0.2909	0.2583	0.2574	0.2019	0.2019	0.2670	0.2608	0.1996	0.1958	0.1972	0.1950	0.1456	0.1448	0.3182	0.3125	0.2751	0.2721	0.2401	0.2388	0.1983	0.1980
				Wood	0.2666	0.2565	0.1941	0.1883	0.1825	0.1806	0.1382	0.1378	0.3310	0.3227	0.2826	0.2788	0.2503	0.2492	0.1975	0.1975	0.2234	0.2183	0.1810	0.1778	0.1691	0.1677	0.1359	0.1354	0.2915	0.2862	0.2602	0.2567	0.2286	0.2275	0.1941	0.1935
		Clips	None	Other	0.3269	0.3135	0.2555	0.2456	0.2040	0.2025	0.1602	0.1595	0.4017	0.3893	0.3377	0.3306	0.2714	0.2696	0.2155	0.2148	0.3193	0.3103	0.2564	0.2513	0.2134	0.2118	0.1677	0.1671	0.3786	0.3712	0.3222	0.3193	0.2671	0.2661	0.2185	0.2185
				Wood	0.2930	0.2799	0.2273	0.2179	0.1923	0.1909	0.1486	0.1478	0.3677	0.3558	0.3119	0.3041	0.2588	0.2574	0.2054	0.2054	0.2704	0.2618	0.2201	0.2152	0.1869	0.1854	0.1514	0.1509	0.3331	0.3259	0.2906	0.2878	0.2432	0.2423	0.2052	0.2052
			Hurricane	Other	0.2429	0.2298	0.2033	0.1962	0.1699	0.1679	0.1371	0.1369	0.3391	0.3301	0.2944	0.2886	0.2489	0.2478	0.1996	0.1994	0.2312	0.2232	0.1979	0.1941	0.1663	0.1649	0.1378	0.1373	0.3126	0.3061	0.2742	0.2715	0.2323	0.2316	0.1969	0.1965
				Wood	0.2223	0.2100	0.1894	0.1840	0.1622	0.1604	0.1335	0.1333	0.3215	0.3138	0.2816	0.2762	0.2449	0.2438	0.1967	0.1966	0.2013	0.1950	0.1801	0.1767	0.1539	0.1527	0.1331	0.1326	0.2882	0.2826	0.2592	0.2567	0.2249	0.2245	0.1934	0.1931
		Wraps	None	Other	0.2981	0.2811	0.2517	0.2408	0.1891	0.1867	0.1599	0.1585	0.3916	0.3783	0.3352	0.3284	0.2686	0.2670	0.2154	0.2148	0.3006	0.2895	0.2541	0.2485	0.2021	0.1998	0.1674	0.1664	0.3738	0.3654	0.3212	0.3172	0.2643	0.2630	0.2183	0.2180
				Wood	0.2622	0.2464	0.2222	0.2124	0.1745	0.1724	0.1480	0.1468	0.3677	0.3445	0.3095	0.3029	0.2555	0.2541	0.2054	0.2053	0.2488	0.2384	0.2173	0.2117	0.1730	0.1708	0.1506	0.1499	0.3267	0.3185	0.2895	0.2852	0.2394	0.2387	0.2048	0.2043
			Hurricane	Other	0.2352	0.2209	0.2031	0.1953	0.1624	0.1607	0.1365	0.1363	0.3379	0.3270	0.2944	0.2885	0.2464	0.2458	0.1995	0.1992	0.2277	0.2195	0.1974	0.1934	0.1602	0.1588	0.1376	0.1371	0.3122	0.3057	0.2741	0.2715	0.2309	0.2303	0.1968	0.1963
				Wood	0.2168	0.2050	0.1887	0.1832	0.1575	0.1563	0.1333	0.1333	0.3215	0.3116	0.2816	0.2761	0.2430	0.2426	0.1967	0.1966	0.1993	0.1925	0.1794	0.1763	0.1515	0.1503	0.1331	0.1325	0.2879	0.2817	0.2589	0.2567	0.2248	0.2239	0.1934	0.1930

Strongest

Table 4-11. Terrain C Loss Relativities (Non-FBC Roof Cover) Normalized to Weakest House

Weakest

Terrain C Single Family					Low Roof Slope (<= 5:12)																Other Roof Slope (>=6:12)											
					Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile				Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile			
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip	
					No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
Non-FBC	A	Toe Nails	None	Other	1.0000	0.8947	0.6563	0.5800	0.6141	0.5750	0.3401	0.3200	0.9154	0.8377	0.6488	0.5958	0.5710	0.5439	0.3616	0.3481	0.7412	0.6768	0.5036	0.4533	0.5243	0.4978	0.3270	0.3115	0.6353	0.5862	0.5031	0.4685	0.4663	0.4490	0.3476	0.3379
				Wood	0.8956	0.7946	0.5822	0.5121	0.5072	0.4700	0.2940	0.2774	0.8143	0.7397	0.5825	0.5328	0.4998	0.4743	0.3211	0.3092	0.6808	0.6239	0.4461	0.4009	0.4367	0.4140	0.2871	0.2754	0.5689	0.5236	0.4471	0.4147	0.4054	0.3906	0.3086	0.3005
			Hurricane	Other	0.7337	0.6040	0.4466	0.3563	0.4365	0.3966	0.2597	0.2409	0.7154	0.6262	0.4751	0.4155	0.4592	0.4322	0.2994	0.2862	0.4135	0.3408	0.3031	0.2478	0.3517	0.3293	0.2370	0.2240	0.4318	0.3800	0.3508	0.3151	0.3568	0.3413	0.2770	0.2689
				Wood	0.6054	0.4741	0.3541	0.2688	0.3123	0.2717	0.1743	0.1565	0.6108	0.5239	0.3975	0.3418	0.3806	0.3539	0.2473	0.2352	0.3018	0.2361	0.2259	0.1795	0.2015	0.1812	0.1566	0.1463	0.3461	0.3001	0.2857	0.2549	0.2701	0.2572	0.2267	0.2204
		Clips	None	Other	0.9109	0.7983	0.6371	0.5607	0.5071	0.4683	0.3113	0.2904	0.8844	0.8062	0.6449	0.5931	0.5426	0.5166	0.3561	0.3427	0.6053	0.5337	0.4768	0.4241	0.4118	0.3854	0.2989	0.2836	0.5973	0.5479	0.4985	0.4645	0.4386	0.4222	0.3415	0.3325
				Wood	0.7928	0.6824	0.5580	0.4873	0.4244	0.3886	0.2596	0.2432	0.7766	0.7005	0.5766	0.5280	0.4696	0.4454	0.3136	0.3027	0.5254	0.4617	0.4135	0.3659	0.3379	0.3176	0.2505	0.2395	0.5224	0.4772	0.4415	0.4097	0.3727	0.3589	0.2999	0.2927
			Hurricane	Other	0.7159	0.5816	0.4453	0.3549	0.3895	0.3478	0.2351	0.2151	0.7154	0.6251	0.4751	0.4155	0.4446	0.4172	0.2940	0.2810	0.3957	0.3165	0.3026	0.2464	0.2906	0.2666	0.2165	0.2032	0.4303	0.3785	0.3505	0.3149	0.3395	0.3243	0.2742	0.2663
				Wood	0.5984	0.4664	0.3540	0.2686	0.3053	0.2644	0.1731	0.1552	0.6108	0.5238	0.3973	0.3417	0.3797	0.3524	0.2470	0.2349	0.2972	0.2293	0.2254	0.1786	0.1955	0.1750	0.1560	0.1453	0.3451	0.3001	0.2852	0.2546	0.2695	0.2558	0.2267	0.2203
		Wraps	None	Other	0.8968	0.7831	0.6368	0.5600	0.4925	0.4539	0.3099	0.2895	0.8803	0.8031	0.6449	0.5931	0.5385	0.5124	0.3561	0.3426	0.5850	0.5110	0.4767	0.4241	0.3971	0.3711	0.2988	0.2831	0.5942	0.5449	0.4984	0.4644	0.4364	0.4201	0.3415	0.3325
				Wood	0.7758	0.6646	0.5572	0.4861	0.4049	0.3703	0.2570	0.2412	0.7716	0.6960	0.5766	0.5280	0.4630	0.4391	0.3136	0.3026	0.4979	0.4324	0.4132	0.3656	0.3173	0.2972	0.2499	0.2386	0.5184	0.4735	0.4415	0.4097	0.3681	0.3546	0.2999	0.2927
			Hurricane	Other	0.7159	0.5816	0.4453	0.3549	0.3806	0.3388	0.2351	0.2148	0.7154	0.6251	0.4751	0.4154	0.4427	0.4156	0.2940	0.2809	0.3954	0.3158	0.3026	0.2463	0.2801	0.2570	0.2162	0.2032	0.4301	0.3784	0.3505	0.3149	0.3387	0.3234	0.2742	0.2663
				Wood	0.5984	0.4664	0.3539	0.2686	0.3039	0.2632	0.1731	0.1552	0.6108	0.5237	0.3973	0.3416	0.3794	0.3524	0.2470	0.2349	0.2972	0.2289	0.2254	0.1784	0.1947	0.1745	0.1560	0.1453	0.3449	0.3001	0.2852	0.2546	0.2695	0.2558	0.2266	0.2203
	B	Toe Nails	None	Other	0.7936	0.7071	0.5355	0.4582	0.5360	0.5036	0.3153	0.2957	0.6823	0.6021	0.5120	0.4494	0.4712	0.4450	0.3294	0.3157	0.7064	0.6460	0.4566	0.4051	0.5110	0.4857	0.3107	0.2942	0.5802	0.5291	0.4477	0.4098	0.4368	0.4179	0.3251	0.3148
				Wood	0.7292	0.6535	0.4875	0.4247	0.4405	0.4127	0.2805	0.2660	0.6245	0.5557	0.4626	0.4069	0.4258	0.4046	0.2953	0.2851	0.6536	0.6029	0.4068	0.3622	0.4283	0.4077	0.2781	0.2661	0.5229	0.4784	0.3939	0.3591	0.3849	0.3701	0.2866	0.2782
			Hurricane	Other	0.4589	0.3623	0.3074	0.2249	0.3526	0.3261	0.2411	0.2249	0.4489	0.3616	0.3602	0.3014	0.3724	0.3494	0.2761	0.2648	0.3564	0.2939	0.2617	0.2115	0.3384	0.2939	0.2251	0.2115	0.3675	0.3176	0.3188	0.2866	0.3316	0.3169	0.2626	0.2547
				Wood	0.3305	0.2420	0.2345	0.1711	0.2181	0.1927	0.1595	0.1462	0.3657	0.2917	0.3045	0.2587	0.2960	0.2755	0.2347	0.2257	0.2464	0.1953	0.1964	0.1607	0.1839	0.1689	0.1506	0.1423	0.2921	0.2535	0.2647	0.2401	0.2515	0.2404	0.2224	0.2166
		Clips	None	Other	0.6115	0.4962	0.4375	0.3316	0.3737	0.3343	0.2533	0.2265	0.5939	0.5004	0.4743	0.3997	0.4138	0.3841	0.3116	0.2957	0.5276	0.4498	0.3854	0.3205	0.3693	0.3392	0.2580	0.2382	0.5075	0.4470	0.4223	0.3786	0.3895	0.3691	0.3092	0.2984
				Wood	0.5420	0.4476	0.3743	0.2817	0.3232	0.2952	0.2069	0.1885	0.5259	0.4437	0.4171	0.3492	0.3645	0.3418	0.2708	0.2589	0.4603	0.3961	0.3223	0.2629	0.3078	0.2884	0.2062	0.1927	0.4362	0.3823	0.3651	0.3234	0.3262	0.3112	0.2628	0.2540
			Hurricane	Other	0.3865	0.2594	0.2982	0.2095	0.2721	0.2394	0.1946	0.1743	0.4374	0.3433	0.3584	0.2984	0.3380	0.3124	0.2634	0.2508	0.3117	0.2357	0.2583	0.2071	0.2545	0.2321	0.1900	0.1756	0.3601	0.3079	0.3172	0.2843	0.3018	0.2857	0.2556	0.2466
				Wood	0.2938	0.1915	0.2308	0.1667	0.1970	0.1686	0.1560	0.1426	0.3612	0.2848	0.3026	0.2560	0.2917	0.2716	0.2341	0.2252	0.2259	0.1712	0.1942	0.1580	0.1707	0.1544	0.1484	0.1403	0.2884	0.2499	0.2618	0.2362	0.2495	0.2385	0.2222	0.2159
		Wraps	None	Other	0.5406	0.4012	0.4252	0.3096	0.3280	0.2795	0.2466	0.2171	0.5696	0.4650	0.4679	0.3898	0.3988	0.3666	0.3077	0.2912	0.4634	0.3688	0.3738	0.3003	0.3270	0.2908	0.2503	0.2285	0.4879	0.4215	0.4167	0.3709	0.3753	0.3540	0.3056	0.2944
				Wood	0.4582	0.3382	0.3597	0.2564	0.2680	0.2336	0.1970	0.1752	0.4958	0.4014	0.4103	0.3388	0.3439	0.3190	0.2653	0.2518	0.3815	0.3000	0.3105	0.2425	0.2507	0.2268	0.1936	0.1773	0.4125	0.3519	0.3594	0.3166	0.3053	0.2893	0.2570	0.2478
			Hurricane	Other	0.3816	0.2481	0.2980	0.2085	0.2443	0.2052	0.1917	0.1695	0.4364	0.3407	0.3576	0.2975	0.3307	0.3036	0.2625	0.2494	0.3089	0.2292	0.2573	0.2052	0.2276	0.2002	0.1876	0.1722	0.3596	0.3066	0.3166	0.2838	0.2950	0.2778	0.2548	0.2458
				Wood	0.2928	0.1874	0.2295	0.1645	0.1942	0.1651	0.1557	0.1423	0.3606	0.2830	0.3017	0.2548	0.2915	0.2707	0.2333	0.2247	0.2239	0.1683	0.1926	0.1555	0.1683	0.1515	0.1481	0.1394	0.2871	0.2479	0.2609	0.2358	0.2489	0.2375	0.2218	0.2156
	C	Toe Nails	None	Other	0.7877	0.7047	0.5355	0.4581	0.5331	0.5018	0.3153	0.2957	0.6687	0.5926	0.5114	0.4484	0.4669	0.4413	0.3293	0.3157	0.7064	0.6447	0.4564	0.4051	0.5109	0.4855	0.3104	0.2940	0.5800	0.5285	0.4470	0.4096	0.4360	0.4175	0.3246	0.3144
				Wood	0.7229	0.6515	0.4875	0.4244	0.4360	0.4105	0.2803	0.2660	0.6158	0.5509	0.4617	0.4063	0.4241	0.4044	0.2953	0.2851	0.6536	0.6018	0.4067	0.3622	0.4283	0.4077	0.2777	0.2659	0.5227	0.4784	0.3933	0.3585	0.3836	0.3694	0.2858	0.2780
			Hurricane	Other	0.4472	0.3577	0.3060	0.2248	0.3519	0.3261	0.2409	0.2248	0.4260	0.3486	0.3585	0.3000	0.3669	0.3468	0.2760	0.2648	0.3564	0.2939	0.2611	0.2110	0.3384	0.2939	0.2250	0.2110	0.3668	0.3170	0.3178	0.2863	0.3309	0.3163	0.2626	0.2547
				Wood	0.3168	0.2374	0.2322	0.1710	0.2138	0.1908	0.1592	0.1462	0.3469	0.2844	0.3023	0.2578	0.2920	0.2745	0.2340	0.2252	0.2457	0.1953	0.1957	0.1607	0.1839	0.1689	0.1506	0.1423	0.2910	0.2530	0.2632	0.2399	0.2513	0.2404	0.2224	0.2166
		Clips	None	Other	0.5929	0.4814	0.4342	0.3265	0.3677	0.3298	0.2526	0.2261	0.5692	0.4783	0.4692	0.3922	0.4036	0.3744	0.3099	0.2948	0.5260	0.4491	0.3840	0.3187	0.3681	0.3381	0.2580	0.2381	0.5062	0.4461	0.4199	0.3766	0.3880	0.3683	0.3083	0.2978
				Wood	0.5285	0.4399	0.3713	0.2787	0.3207	0.2962	0.2063	0.1885	0.5053	0.4279	0.4121	0.3425	0.3588	0.3372	0.2696	0.2581	0.4582	0.3960	0.3207	0.2613	0.3056	0.2869	0.2061	0.1920	0.4362	0.3823	0.3618	0.3215	0.3256	0.3109	0.2619	0.2533
			Hurricane	Other	0.3688	0.2436	0.2949	0.2068	0.2654	0.2355	0.1942	0.1741	0.4085	0.3242	0.3559	0.2958	0.3304	0.3067	0.2627	0.2501	0.3103	0.2348	0.2583	0.2071	0.2545	0.2320	0.1900	0.1755	0.3595	0.3077	0.3166	0.2837	0.3006	0.2849	0.2554	0.2464
				Wood	0.2686	0.1821	0.2281	0.1652	0.1911	0.1658	0.1557	0.1424	0.3391	0.2746	0.3012	0.2554	0.2872	0.2685	0.2336	0.2245	0.2242	0.1709	0.1939	0.1579	0.1704	0.1537	0.1484	0.1403	0.2879	0.2496	0.2615	0.2362	0.2491	0.2380	0.2222	0.2159
		Wraps	None	Other	0.5123	0.3742	0.4169	0.2950	0.3164	0.2680	0.2453	0.2154	0.5377	0.4337	0.4589	0.3750	0.3862	0.3540	0.3060	0.2899	0.4622	0.3675	0.3703	0.2966	0.3266	0.2901	0.2493	0.2273	0.4858	0.4186	0.4141	0.3664	0.3747	0.3530	0.3048	0.2935
				Wood	0.4350	0.3198	0.3496	0.2421	0.2586	0.2272	0.1952	0.1736	0.4680	0.3759	0.4008	0.3244	0.3340	0.3103	0.2633	0.2505	0.3808	0.2991	0.3071	0.2385	0.2500	0.2259	0.1930	0.1762	0.4096	0.3488	0.3562	0.3115	0.3049	0.2885	0.2555	0.2463
			Hurricane	Other	0.3487	0.2263	0.2935	0.2048	0.2341	0.1983	0.1911	0.1690	0.4054	0.3198	0.3549	0.2941	0.3209	0.2952	0.2616	0.2486	0.3064	0.2276	0.2569	0.2052	0.2264	0.1997	0.1876	0.1722	0.3578	0.3056	0.3158	0.2826	0.2939	0.2770	0.2540	0.2454
				Wood	0.2660	0.1776	0.2259	0.1628	0.1864	0.1620	0.1555	0.1423	0.3376	0.2731	0.2992	0.2531	0.2861	0.2678	0.2330	0.2241	0.2221	0.1671	0.1909	0.1555	0.1678	0.1515	0.1481	0.1394	0.2863	0.2474	0.2604	0.2343	0.2483	0.2370	0.2213	0.2156

Table 4-12. Terrain C Loss Relativities (FBC Roof Cover) Normalized to Weakest House

Terrain C Single Family					Low Roof Slope (<= 5.12)																Other Roof Slope (>=6:12)															
					Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile				Two Story non-Tile				One Story non-Tile				Two Story Tile				One Story Tile			
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip		Other		Hip	
					No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
FBC	A	Toe Nails	None	Other	0.8597	0.8338	0.5381	0.5252	0.5354	0.5203	0.2792	0.2740	0.7405	0.7219	0.5011	0.4913	0.4439	0.4357	0.2631	0.2605	0.6523	0.6314	0.4164	0.4079	0.4667	0.4540	0.2742	0.2700	0.5128	0.5004	0.3873	0.3815	0.3649	0.3592	0.2586	0.2563
				Wood	0.7635	0.7374	0.4738	0.4599	0.4257	0.4131	0.2386	0.2329	0.6471	0.6282	0.4436	0.4336	0.3784	0.3698	0.2292	0.2262	0.5983	0.5759	0.3657	0.3566	0.3835	0.3713	0.2413	0.2358	0.4575	0.4441	0.3371	0.3312	0.3138	0.3071	0.2257	0.2228
			Hurricane	Other	0.5546	0.5400	0.3057	0.2978	0.3484	0.3396	0.1996	0.1954	0.5164	0.5039	0.3166	0.3095	0.3309	0.3257	0.2030	0.2011	0.3011	0.2927	0.2067	0.2024	0.2952	0.2872	0.1844	0.1814	0.2976	0.2911	0.2366	0.2330	0.2579	0.2539	0.1906	0.1891
				Wood	0.4227	0.4098	0.2210	0.2128	0.2169	0.2135	0.1128	0.1112	0.4150	0.4031	0.2479	0.2410	0.2476	0.2455	0.1533	0.1524	0.1967	0.1892	0.1405	0.1359	0.1375	0.1354	0.1043	0.1034	0.2224	0.2167	0.1808	0.1774	0.1731	0.1715	0.1443	0.1437
		Clips	None	Other	0.7479	0.7319	0.5118	0.5037	0.4149	0.4080	0.2425	0.2409	0.6966	0.6838	0.4937	0.4856	0.4080	0.4035	0.2555	0.2541	0.4961	0.4850	0.3807	0.3761	0.3420	0.3373	0.2399	0.2385	0.4626	0.4545	0.3810	0.3770	0.3331	0.3299	0.2500	0.2491
				Wood	0.6345	0.6181	0.4403	0.4318	0.3381	0.3306	0.1969	0.1948	0.5942	0.5815	0.4343	0.4261	0.3411	0.3368	0.2191	0.2176	0.4260	0.4143	0.3219	0.3175	0.2763	0.2703	0.1974	0.1958	0.3958	0.3876	0.3282	0.3246	0.2763	0.2724	0.2139	0.2129
			Hurricane	Other	0.5263	0.5144	0.3049	0.2973	0.2915	0.2865	0.1697	0.1678	0.5120	0.5006	0.3162	0.3095	0.3110	0.3077	0.1963	0.1953	0.2754	0.2680	0.2059	0.2013	0.2228	0.2192	0.1600	0.1590	0.2963	0.2890	0.2366	0.2329	0.2370	0.2346	0.1862	0.1856
				Wood	0.4126	0.4004	0.2207	0.2124	0.2079	0.2051	0.1111	0.1095	0.4130	0.4018	0.2476	0.2410	0.2459	0.2438	0.1530	0.1518	0.1896	0.1821	0.1393	0.1348	0.1288	0.1272	0.1030	0.1022	0.2221	0.2163	0.1807	0.1773	0.1720	0.1703	0.1439	0.1435
		Wraps	None	Other	0.7262	0.7136	0.5113	0.5037	0.3954	0.3919	0.2425	0.2409	0.6907	0.6785	0.4937	0.4856	0.4035	0.3998	0.2551	0.2534	0.4672	0.4596	0.3805	0.3761	0.3224	0.3196	0.2390	0.2380	0.4571	0.4504	0.3810	0.3769	0.3283	0.3259	0.2500	0.2490
				Wood	0.6104	0.5978	0.4397	0.4318	0.3146	0.3105	0.1969	0.1948	0.5885	0.5763	0.4343	0.4260	0.3344	0.3310	0.2183	0.2164	0.3897	0.3821	0.3219	0.3175	0.2513	0.2479	0.1960	0.1949	0.3888	0.3824	0.3281	0.3243	0.2699	0.2672	0.2139	0.2129
			Hurricane	Other	0.5256	0.5138	0.3049	0.2973	0.2827	0.2796	0.1695	0.1678	0.5120	0.5006	0.3162	0.3095	0.3082	0.3056	0.1963	0.1952	0.2744	0.2670	0.2058	0.2013	0.2094	0.2074	0.1598	0.1590	0.2950	0.2889	0.2366	0.2329	0.2355	0.2336	0.1861	0.1856
				Wood	0.4126	0.4004	0.2207	0.2124	0.2074	0.2047	0.1111	0.1095	0.4129	0.4018	0.2476	0.2410	0.2451	0.2430	0.1530	0.1518	0.1892	0.1814	0.1392	0.1347	0.1286	0.1270	0.1030	0.1022	0.2215	0.2160	0.1807	0.1773	0.1717	0.1703	0.1439	0.1435
	B	Toe Nails	None	Other	0.6898	0.6633	0.4286	0.4145	0.4696	0.4545	0.2584	0.2532	0.5389	0.5201	0.3790	0.3685	0.3567	0.3486	0.2356	0.2330	0.6265	0.6058	0.3747	0.3656	0.4542	0.4416	0.2586	0.2542	0.4680	0.4558	0.3382	0.3327	0.3417	0.3362	0.2376	0.2357
				Wood	0.6361	0.6094	0.3933	0.3790	0.3768	0.3645	0.2291	0.2232	0.4968	0.4778	0.3391	0.3285	0.3187	0.3105	0.2088	0.2058	0.5846	0.5624	0.3318	0.3225	0.3756	0.3637	0.2312	0.2257	0.4192	0.4062	0.2898	0.2839	0.2996	0.2927	0.2049	0.2026
			Hurricane	Other	0.3318	0.3166	0.1893	0.1804	0.2855	0.2768	0.1847	0.1804	0.2925	0.2792	0.2282	0.2208	0.2584	0.2530	0.1855	0.1836	0.2604	0.2529	0.1741	0.1699	0.2604	0.2529	0.1741	0.1699	0.2501	0.2439	0.2141	0.2112	0.2396	0.2360	0.1784	0.1774
				Wood	0.2093	0.1955	0.1338	0.1262	0.1441	0.1407	0.1038	0.1027	0.2230	0.2110	0.1852	0.1794	0.1820	0.1795	0.1459	0.1452	0.1592	0.1536	0.1227	0.1193	0.1246	0.1229	0.1011	0.1004	0.1868	0.1814	0.1687	0.1663	0.1604	0.1595	0.1416	0.1412
		Clips	None	Other	0.4708	0.4508	0.2993	0.2872	0.2913	0.2841	0.1850	0.1829	0.4310	0.4149	0.3255	0.3150	0.2884	0.2834	0.2132	0.2116	0.4208	0.4082	0.2868	0.2801	0.2998	0.2943	0.1984	0.1967	0.3820	0.3726	0.3054	0.3006	0.2867	0.2841	0.2194	0.2184
				Wood	0.4228	0.4035	0.2485	0.2366	0.2531	0.2458	0.1470	0.1450	0.3743	0.3588	0.2771	0.2666	0.2494	0.2446	0.1783	0.1769	0.3664	0.3538	0.2278	0.2215	0.2499	0.2439	0.1528	0.1513	0.3190	0.3099	0.2522	0.2476	0.2328	0.2298	0.1782	0.1774
			Hurricane	Other	0.2332	0.2131	0.1764	0.1652	0.1946	0.1891	0.1322	0.1305	0.2746	0.2599	0.2252	0.2175	0.2177	0.2146	0.1701	0.1689	0.2024	0.1941	0.1709	0.1664	0.1905	0.1870	0.1341	0.1330	0.2407	0.2344	0.2121	0.2087	0.2039	0.2023	0.1696	0.1686
				Wood	0.1642	0.1453	0.1300	0.1218	0.1215	0.1180	0.0996	0.0986	0.2159	0.2033	0.1832	0.1768	0.1769	0.1747	0.1452	0.1445	0.1353	0.1289	0.1199	0.1167	0.1097	0.1082	0.0985	0.0979	0.1824	0.1776	0.1660	0.1629	0.1574	0.1568	0.1411	0.1404
		Wraps	None	Other	0.3742	0.3548	0.2781	0.2641	0.2333	0.2280	0.1756	0.1732	0.3956	0.3789	0.3150	0.3049	0.2688	0.2649	0.2083	0.2067	0.3398	0.3281	0.2673	0.2602	0.2494	0.2456	0.1878	0.1862	0.3543	0.3451	0.2969	0.2920	0.2706	0.2680	0.2148	0.2142
				Wood	0.3117	0.2933	0.2243	0.2108	0.1870	0.1821	0.1331	0.1311	0.3336	0.3173	0.2659	0.2560	0.2232	0.2197	0.1709	0.1696	0.2697	0.2585	0.2086	0.2013	0.1851	0.1817	0.1370	0.1355	0.2864	0.2774	0.2446	0.2393	0.2094	0.2070	0.1706	0.1700
			Hurricane	Other	0.2249	0.2020	0.1747	0.1630	0.1581	0.1535	0.1272	0.1253	0.2732	0.2575	0.2245	0.2165	0.2080	0.2048	0.1685	0.1676	0.1966	0.1868	0.1692	0.1642	0.1576	0.1550	0.1307	0.1296	0.2393	0.2329	0.2106	0.2074	0.1960	0.1941	0.1684	0.1678
				Wood	0.1616	0.1419	0.1283	0.1195	0.1180	0.1141	0.0993	0.0981	0.2147	0.2015	0.1823	0.1756	0.1763	0.1737	0.1452	0.1445	0.1324	0.1253	0.1174	0.1140	0.1081	0.1064	0.0978	0.0971	0.1806	0.1755	0.1643	0.1616	0.1571	0.1561	0.1403	0.1401
	C	Toe Nails	None	Other	0.6875	0.6618	0.4286	0.4145	0.4693	0.4542	0.2584	0.2531	0.5275	0.5095	0.3780	0.3673	0.3514	0.3441	0.2355	0.2329	0.6256	0.6050	0.3739	0.3649	0.4540	0.4412	0.2572	0.2528	0.4670	0.4547	0.3381	0.3318	0.3410	0.3354	0.2376	0.2357
				Wood	0.6361	0.6094	0.3933	0.3790	0.3743	0.3619	0.2290	0.2231	0.4883	0.4706	0.3378	0.3273	0.3168	0.3095	0.2078	0.2050	0.5829	0.5607	0.3316	0.3220	0.3756	0.3637	0.2301	0.2244	0.4190	0.4061	0.2898	0.2839	0.2978	0.2914	0.2049	0.2026
			Hurricane	Other	0.3251	0.3116	0.1878	0.1794	0.2842	0.2759	0.1847	0.1794	0.2784	0.2669	0.2263	0.2193	0.2554	0.2506	0.1852	0.1832	0.2603	0.2527	0.1739	0.1698	0.2603	0.2527	0.1739	0.1698	0.2500	0.2437	0.2140	0.2107	0.2393	0.2360	0.1782	0.1771
				Wood	0.2019	0.1908	0.1333	0.1261	0.1410	0.1385	0.1035	0.1026	0.2132	0.2038	0.1842	0.1781	0.1794	0.1772	0.1458	0.1450	0.1592	0.1532	0.1224	0.1192	0.1243	0.1227	0.1007	0.1002	0.1868	0.1814	0.1687	0.1662	0.1600	0.1595	0.1416	0.1410
		Clips	None	Other	0.4566	0.4375	0.2955	0.2830	0.2854	0.2786	0.1843	0.1821	0.4108	0.3953	0.3203	0.3094	0.2807	0.2761	0.2122	0.2106	0.4197	0.4071	0.2856	0.2789	0.2996	0.2938	0.1984	0.1967	0.3809	0.3717	0.3047	0.2991	0.2867	0.2840	0.2192	0.2181
				Wood	0.4131	0.3946	0.2457	0.2336	0.2501	0.2435	0.1469	0.1449	0.3597	0.3448	0.2714	0.2604	0.2467	0.2419	0.1771	0.1760	0.3649	0.3523	0.2270	0.2207	0.2498	0.2434	0.1528	0.1513	0.3179	0.3091	0.2509	0.2458	0.2328	0.2298	0.1782	0.1768
			Hurricane	Other	0.2128	0.1977	0.1729	0.1619	0.1895	0.1848	0.1319	0.1305	0.2553	0.2427	0.2223	0.2148	0.2123	0.2093	0.1693	0.1684	0.2015	0.1933	0.1701	0.1654	0.1905	0.1869	0.1341	0.1330	0.2406	0.2342	0.2117	0.2085	0.2033	0.2016	0.1691	0.1680
				Wood	0.1500	0.1376	0.1280	0.1204	0.1177	0.1152	0.0993	0.0983	0.2046	0.1948	0.1816	0.1758	0.1738	0.1721	0.1450	0.1445	0.1345	0.1281	0.1199	0.1164	0.1096	0.1079	0.0985	0.0979	0.1824	0.1772	0.1655	0.1627	0.1574	0.1565	0.1411	0.1404
		Wraps	None	Other	0.3485	0.3292	0.2677	0.2507	0.2229	0.2176	0.1742	0.1716	0.3670	0.3505	0.3046	0.2923	0.2574	0.2534	0.2072	0.2058	0.3379	0.3261	0.2644	0.2565	0.2489	0.2447	0.1873	0.1857	0.3520	0.3431	0.2936	0.2882	0.2699	0.2674	0.2146	0.2139
				Wood	0.2923	0.2744	0.2141	0.1980	0.1816	0.1773	0.1316	0.1296	0.3104	0.2945	0.2558	0.2440	0.2157	0.2122	0.1698	0.1687	0.2677	0.2565	0.2053	0.1977	0.1848	0.1809	0.1357	0.1342	0.2844	0.2756	0.2408	0.2356	0.2087	0.2062	0.1701	0.1693
			Hurricane	Other	0.1994	0.1809	0.1713	0.1599	0.1512	0.1475	0.1263	0.1244	0.2508	0.2381	0.2212	0.2130	0.2007	0.1978	0.1678	0.1665	0.1950	0.1860	0.1685	0.1640	0.1571	0.1544	0.1305	0.1293	0.2382	0.2319	0.2102	0.2066	0.1953	0.1932	0.1677	0.1671
				Wood	0.1449	0.1318	0.1256	0.1178	0.1136	0.1113	0.0991	0.0981	0.2027	0.1926	0.1802	0.1736	0.1733	0.1714	0.1448	0.1438	0.1314	0.1250	0.1170	0.1137	0.1076	0.1061	0.0976	0.0970	0.1803	0.1755	0.1640	0.1605	0.1571	0.1557	0.1402	0.1398

Strongest

The strongest house for Terrain B has a relativity of 0.1325 and the strongest house in Terrain C has a relativity of 0.0970. Both of these strong houses correspond to a one-story hip, 7:12 slope, SWR, FBC shingle, Deck C, Wraps, Hurricane opening protection, and wood soffits. These relativities appear very low because they are normalized to the weakest of the weak, rather than a typical house. As pointed out in the previous section, these houses have loss costs that are about 2.5 to 3 times lower than a typical house in their respective terrains (see Table 4-4 through Table 4-7).

Pair-wise Comparisons. One-at-a-time pair-wise comparisons of each feature have been computed by comparing the same house with and without a particular feature. For example, houses with and without SWR, houses with hip roof shape vs. houses with other roof shape, 2 story homes vs. 1 story homes, etc. Each terrain table has 2304 entries. In pair-wise comparison of complements, there are 1152 such comparisons. For features with 3 possible levels each (roof deck and roof-to-wall), we analyzed the difference between the weakest and the strongest level, so that these were also reduced to a single pair-wise comparison. Table 4-13 summarizes the mean, minimum, and maximum statistics of these pair-wise comparisons. Table 4-13 shows loss increases, which were obtained by dividing the "weak" case by the "strong" case. For example, we note that the pair-wise loss increase statistics for Roof Deck C to Roof Deck A include the following effects:

1. The average pair-wise loss increase (C to A) is 22% in Terrain B and 34% in Terrain C.[28]
2. The minimum change in loss increase is 0.7% in B and 1.5% in C. That is, if we search through the table to find the minimal loss increase, we find a house (1-story tile, hip, 7:12, no SWR, FBC, wrap, hurricane protection, and wood soffits) where the mitigation would produce only a 0.7% loss increase in Terrain B. For this house, the effect of the tile weight is to help hold the roof deck down, the hip roof and 7:12 roof slope minimize the loads on the deck, and no SWR tends to minimize the effect of deck strength. All those factors combine to minimize the effect of deck strength for this house.
3. The maximum change in roof deck C to A loss increase change is 148% in Terrain B. This corresponds to a house with 2-stories, 4:12, shingle, gable, SWR, FBC, wrap, hurricane protection, other soffits. For this house, changes in roof deck strength makes a large difference since the house has 2-stories, a gable roof, SWR, shingle roof cover, and weak soffits.

Thus, there is a wide range of impact of pair-wise mitigation since the minimum and maximum loss increase impacts differ by large amounts. This type of result is generally expected in "serial systems" (vs. "parallel" or redundant systems) in which any weakness in the main components of the system can produce failure. That is, if there is a weak link in the building envelope, the impact of mitigating that feature can notably reduce the loss costs for that building. Hence, the maximum impacts are very large in those cases.

The average impacts in Table 4-13 indicate that number of stories, roof cover, opening protection, roof shape, and roof deck are major contributors to loss differentials. These impacts and order should be expected to change somewhat regionally within the state, so Table 4-13 should be viewed only as an approximate indication of mitigation effectiveness.

The data in Table 4-13 are plotted in Figure 4-3. These figures illustrate that the maximum impacts are dramatic for each individual mitigation feature. These maximum impacts generally occur when the house has good features except for the one weak feature. They underscore the general nonlinear relationship of the mitigation features and that mitigation is best undertaken with consideration of the existing construction features on a building.

[28] These averages are unweighted averages across all complementary pair-wise cells in the loss relativity table. The average does not necessarily correspond to the average loss reduction effect for mitigated houses in Florida because the cells were not weighted according by the building stock distribution.

Table 4-13. Mitigation Feature Pair-wise Comparison of Loss Increases

Mitigation Feature	Terrain B			Terrain C		
	Min	Avg	Max	Min	Avg	Max
No SWR/SWR	0.0%	6.5%	41.9%	0.1%	8.0%	56.2%
Gable/Hip	7.7%	31.6%	107.7%	5.1%	35.3%	92.6%
2 Story/1 Story	19.3%	51.1%	131.1%	0.0%	40.8%	123.6%
Tile /Shingle	-8.2%	30.6%	56.1%	-28.3%	15.6%	65.3%
4:12/7:12	-6.6%	15.4%	104.1%	12.5%	16.3%	120.7%
Soffits: Other/Wood	0.8%	7.4%	21.7%	7.1%	24.5%	114.7%
Op. Prot: None/Hur	2.5%	17.8%	70.2%	11.8%	61.1%	267.2%
Rf-Wall: Toe Nail/Wrap	0.0%	8.2%	78.0%	0.0%	16.6%	78.0%
Rf Deck: A/C	0.7%	22.3%	148.1%	1.5%	33.7%	203.8%
Rf Cover: non FBC/FBC	17.3%	50.9%	91.2%	6.5%	36.4%	83.6%

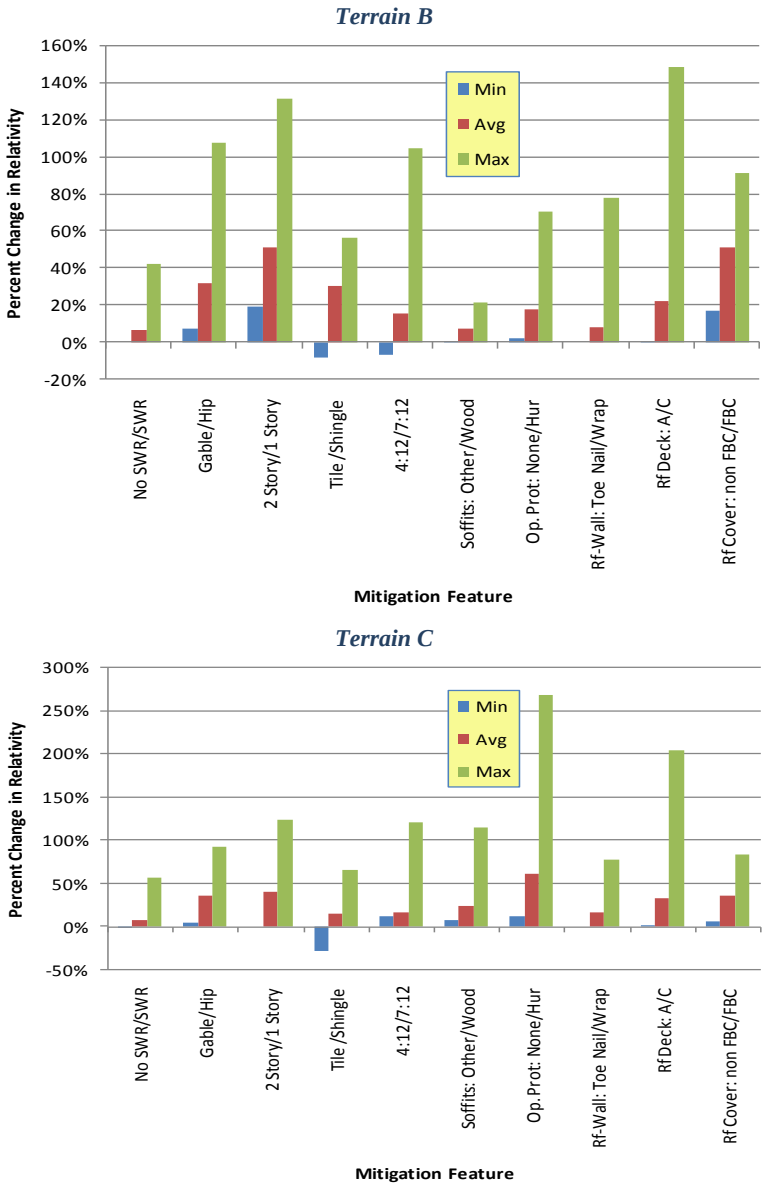


Figure 4-3. Pair-wise Loss Increase Min, Average, and Max Statistics

Two features have both positive and negative impacts. These are roof slope and roof cover type:

1. Roofs with 4:12 slopes are generally worse than 7:12 roofs, as seen by the average loss increase of 15% in Terrain B and 16% in Terrain C. However, a 4:12 roof slope is slightly better (up to 6.6%) for about 4% of the cells in Terrain B. These cases are dominated by roof height (7:12s are taller than 4:12s) and whole roof failures. These houses typically are toe-nailed or clipped, shingle roof covers (less weight), FBC, no shutters and weak soffits.

2. Tile roof covers are better than shingles for certain situations in both Terrain B and Terrain C. Tile roof covers weigh more and help hold the roof down when the roof deck and roof-to-wall connections are weak. However, when these connections are strong, shingle roof covers are generally much better. Tiles are better than shingles in 3.6% of the Terrain B cases and 24% of the Terrain C cases. Since the loads on two-story buildings are larger, we see that tile roofs help in some of these cases. However, one should not infer from this pair-wise comparison that one should consider going from a shingle to a tile roof as a mitigation-based decision. In all cases, if you improved the roof strength on the shingle house and shutter it, you will reduce the loss costs significantly over the same house with a tile roof cover.

The maximum of the pair-wise loss increase (weak/strong) comparisons are shown in Figure 4-3. The maximum corresponds to the house where the pair-wise difference in loss relativity is the greatest. For example, the maximum effect of removing shutters is 256% increase in loss costs for a Terrain C house (2 story shingle, 7:12 slope, gable, no SWR, toe nail, deck B, FBC roof cover, wood soffits). We see that there the maximum difference is 40% or greater for most features. The single exception is soffits in Terrain B (22% maximum increase). Hence, even in cases where the average increase for a feature is relatively modest, we see that the maximum increases are significant. This characteristic of these tables reflect the fact that if the house has good or strong features for all but one feature, the importance of that final feature is critical in achieving the loss reduction mitigation potential of the building.

Based on the fact that the maximum impacts are all significant, we do not believe that further simplification of the loss relativity tables is warranted.

Statistical Analysis. We performed a general linear statistical analysis of the Terrain B and Terrain C tables normalized to the weakest house. We used the Statistical Analysis System (SAS, 1992) PROC GLM (PROCedure for General Linear Models) to do ANOVA (Analysis of Variance). ANOVA is a standard method of analysis that allows for variation in a response measure (loss relativities), arising from more than one antecedent variable, considering all variables together. Hence, this analysis is not limited to the pair-wise one at a time comparisons discussed in the preceding paragraphs. [29]

Table 4-14 shows the results of the analysis. Each variable has been ranked according to its F-value, which is a measure of how much of the variation in the loss relativities is explained by that variable in the presence of variation of all the other variables. We see that the simple first order model explains about 80% of the variance in the loss relativity tables.[30] The ranking of the variables depends on the terrain, but 4 of the first 5 ranked variables are the same for both terrains. Roof-related variables dominate these rankings. Overall, these results generally agree with the pair-wise, one-at-a-time comparisons.

[29] Additional information independent of SAS can be found online at the NIST Handbook of Statistical Methods http://www.itl.nist.gov/div898/handbook/index.htm particularly at Multi- factor Analysis of Variance http://www.itl.nist.gov/div898/handbook/eda/section3/eda355.htm

[30] When we included cross terms in the analysis, the r^2 values increased to more than 87%.

Table 4-14. Results of General Linear Model Statistical Analysis

Statistic	*Terrain B*	*Terrain C*
Rank	No. Stories FBC/non-FBC Roof Shape Roof Cover Roof Deck Roof Slope Opening Prot. SWR Soffits Roof-to-Wall	Opening Prot. No. Stories Roof Shape FBC/non-FBC Roof Deck Soffits Roof-to-Wall Roof Slope SWR Roof Cover
r^2	81%	79 %

These analyses illustrates that the ranking of importance of mitigation features are terrain dependent. We also believe similar approaches to "ranking" would produce different results in different parts of the state. That is, the rankings shouldn't be expected to be robust across 10 mitigation features since the hazard risk varies significantly by location within the state. Further due to the "serial system" nature of building envelope performance, small changes in hazard risk or terrain can lead to big changes in relative importance. These results confirm that in terms of wind loss mitigation, the building envelope features are all significant.

4.2.5 Secondary Mitigation Factors

The analysis of secondary factors follows the work that was done in 2002. We employ many of the factors from the 2002 studies, studies on wood panel shutters, and the more recent HSRS study. We have performed new analysis on secondary factors for three features: (1) window and door leak potential; (2) double wrap roof-to-wall connections; and (3) reinforced-concrete roof deck integral with reinforced-masonry or concrete walls.

Table 4-15 provides a summary of the secondary factors that should be used with single family residences. These factors should be applied to the appropriate loss relativity from the primary tables according to:

$$R' = R\,K^{(1-R)} \qquad \textit{(4-1a)}$$

$$K = \prod_{i=1}^{n} K_i \qquad \textit{(4-1b)}$$

where R' = updated relativity due to secondary factors, K_i = secondary adjustment factors given in Table 4-15, K = aggregate product of all secondary factors, and R = relativity for the basic house features from Table 4-9 through Table 4-12. If an interpolation for opening protection is needed, then such interpolation should be completed to determine R (using Equation (4-2) prior to the use of Equation (4-1). Equation (4-1) is valid for relativities normalized to the weakest house. It is slightly different from the formula for secondary factors presented in the 2002 studies in that the final K factor is raised to the $(1\text{-}R)$ power. The exponent form in Equation (4-1) provides more consistency with the fact that the stronger houses are more sensitive to secondary factors whereas the weaker houses have so many other problems that the secondary factor effects are less important. For $R = 1$ (the weakest house), the effect of secondary factors is null and as $R \rightarrow 0$, $R' \rightarrow 0$. Equation (4-1) is a simple way to achieve the desired effect without overcomplicating the application of secondary factors. No capping is needed for Equation (4-1) as the resulting R' is bounded by [0, 1] for R bounded by [0, 1] and positive K.

Table 4-15. Single Family Secondary Factors (K_i).

No.	*Secondary Factor Description*	*Applies to post-FBC era?*	*Loss Relativity Multiplier (K_i)*	*Comments*
1	Dimensional Lumber Deck	Yes	0.96	Based on 2002 study. Applies to Deck C.
2	Unreinforced Masonry Walls	No	0.98	Based on 2002 study.
3	Reinforced Masonry Walls	Yes	0.95	Based on 2002 study; Secondary Factors 2 and 3 are mutually
4	Opening Coverage – All Openings[1]	Yes (Except not in HVHZ)	0.98	Based on 2002 study. Applies to Hurricane Protection Level; does not apply to other levels.
5	Unbraced Gable End	No	1.02	Based on 2002 study.
6	Foundation Restraint	No	Ter B: 1.38; Ter C: 1.54	Based on 2002 study.
7	Reinforced Concrete Roof Deck Integral with Concrete or Reinforced Masonry Walls	Yes	See Table 4-16	Based on new sensitivity study. Note that Factors 1, 2, 3, 5, 6, 8 10 and 12 do not apply to reinforced concrete roof decks.
8	Enhanced Wood Panel Roof Deck (≥ 5/8 " plywood with 2½ inch screws or 8d ring-shank nails)	Yes	0.96	(Secondary Factor 1 and 8 are mutually exclusive.) Applies to Deck C.
9	Shutter Interpolation Between None and Hurricane	Yes	Ordinary: Terrain B S = 0.72, Terrain C S = 0.56; OSB: Terrain B S = 0.72, Terrain C S = 0.56; Plywood: Terrain B S = 0.48, Terrain C S = 0.46; Basic: Terrain B S = 0.23, Terrain C S = 0.19	Based on 2003-2004 DCA Shutter Impact Tests for OSB and Plywood. Values given are shutter interpolation factors (S). (See Eq. 4-2).
10	Vinyl Siding	Yes	1.02	Based on HSRS study.
11	Window, Door, and Skylight Water Leak Potential[2]	Yes		Based on new sensitivity study. Count the number of openings in each category. All doors are counted as other type. Determine the appropriate factor for each type and multiply the factors together.
	Total Number of Openings a. Casement and Fixed		Other / Non-Porous Shutters	
	0		1.00 / 1.00	
	1 to 10		1.03 / 1.01	
	11 to 20		1.05 / 1.03	
	21 to 30		1.08 / 1.06	
	≥ 31		1.11 / 1.09	
	b. All Other Window/Door Types			
	0		1.00 / 1.00	
	1 to 10		1.04 / 1.02	
	11 to 20		1.07 / 1.04	
	21 to 30		1.11 / 1.08	
	≥ 31		1.14 / 1.11	
12	Double Wrap Roof-to-Wall Connector	No	Opening Prot. / Terrain B / Terrain C All Others / 0.98 / 0.93 Basic, Hurricane / 0.99 / 0.97	Based on new sensitivity study. Does not apply to post-FBC constructions.
13	Roof Cover Age Interpolation	Yes	Type / A(yrs) Tile, Cement, Slate Metal / 20 Other / 15	Use Equation (4-3a) to interpolate from FBC to non-FBC Roof Cover. (N=Age of roof in years.)
14	Partially Enclosed Designs	Yes	0.98	Applies to post-FBC era, partially enclosed designs in WBD region. Apply to "Opening Protection = None."

[1] All openings protected factor shall only be used when all openings (including non-glazed) are protected to "Hurricane."

[2] Each sliding glass door is counted as 4 "other" openings in determining the total number of openings. All other openings (doors, windows and skylights) are counted as one each.

The following paragraphs discuss the new work on secondary factors.

Reinforced Concrete Roof Decks (No. 7). We simulated houses with reinforced concrete roof decks integrally tied into reinforced concrete walls or reinforced masonry walls. These houses have significant roof strength and implied secondary water resistance. We simulated two types of roof cover: a painted (epoxy type roof finish) and a mortared tile roof cover. The FBC roof cover corresponds to new painted finish and new tile roofs in excellent condition. The non-FBC roof cover corresponds to painted finish with some observable cracks or a mortared tile with some wear on it and some cracking of the tile mortar or epoxy. A mortared tile roof cover on a reinforced concrete roof deck that is in very bad condition should not qualify for mitigation rate differentials until the roof cover is replaced.

Table 4-16 shows the loss relativities for reinforced concrete roof deck houses. These loss relativities correspond to a 10 to 15% loss reduction over the strongest wood frame house in Table 4-6 though Table 4-9. The reduction in loss over the strongest wood frame or masonry wall house is due to the fact that the roof decks and roof-to-wall connections of these buildings should not fail in the most severe storms.

Table 4-16. Loss Relativities for Reinforced Concrete Roof Decks Integrally Tied to Reinforced Concrete or Masonry Walls[1]

Terrain	Roof Cover	Opening Prot.	Painted Roof		Tile Roof			
			Two-Story	One-Story	Two-Story		One Story	
					Other	Hip	Other	Hip
B	Non-FBC	None[2]	0.2079	0.1484	0.4409	0.3594	0.3598	0.2749
		Hurricane	0.1791	0.1373	0.4018	0.3422	0.3348	0.2674
	FBC	None[2]	0.1838	0.1264	0.3111	0.2755	0.2264	0.1821
		Hurricane	0.1577	0.1173	0.2752	0.2480	0.2166	0.1739
C	Non-FBC	None[2]	0.1788	0.1171	0.3127	0.2948	0.2597	0.2179
		Hurricane	0.1066	0.0904	0.2436	0.2260	0.2166	0.1961
	FBC	None[2]	0.1672	0.1026	0.2450	0.2217	0.1776	0.1467
		Hurricane[3]	0.0949	0.0790	0.1718	0.1550	0.1499	0.1258

[1.] The Secondary Factors applicable to this table include Numbers 4, 9, 10, 11, and 13 from Table 4-15.
[2.] For partially enclosed designs, apply a Secondary Factor K_i = 0.98 to these rows.
[3.] For post-FBC construction in the HVHZ, apply Secondary Factor No. 4.

Table 4-16 is applicable for both pre- and Post-FBC construction. For Post-FBC construction in the HVHZ, Secondary Factor 4 should be applied to the results in Table 4-16. If a house with reinforced concrete roof deck was built as partially enclosed in the WBD region, apply a secondary factor of 0.98 (Secondary Factor 14) to the "Opening Protection = None" values in Table 4-16.

Enhanced Wood Panel Roof Deck (No. 8). Plywood panels ≥ ⅝ inches thick and attached with 2½ inch screws or Bd ring shank inch nails and Deck C fastening spacing qualifies for "Enhanced Wood Panel Roof Deck." The value of 0.96 in Table 4-15 is based on the 2002 analyses for dimensional lumber, roof decks, which has similar strength.

Opening Protection Interpolation (No. 9). Opening protection refers to protection of openings from wind-borne debris impacts. Openings include windows, doors, garage doors, skylights, etc. Glazed openings are particularly vulnerable to failure from wind-borne debris impacts.[31] Non-glazed openings (such as solid wood exterior doors) are less vulnerable to catastrophic failure from wind-borne debris impacts. The loss relativity tables have been developed with and without opening protection for glazed

[31] Glazing refers to glass or transparent or translucent plastic sheet used in windows, doors, or skylights (ASCE 7-98, Section 6.2).

openings. A secondary factor is applied if all openings (including non-glazed openings) are protected for wind-borne debris impacts.

We did not include intermediate levels of protection in the simulations in this study to help control the size of the main tables and to avoid additional computer runs (another shutter level would have increased the number of runs and the size of the tables by 50%). Our suggested approach is to use interpolation for intermediate levels of opening protection.

The 2008 relativity tables include "none" and "hurricane" levels for opening protection. The hurricane level of protection corresponds to the impact resistance required for the 9 lb 2″× 4″wood stud traveling at 50 fps. This impact level is consistent with the Miami-Dade test standards and the ASTM standards. In the 2002 studies, we included a "Basic" level of protection, which corresponded to the 4.5 lb 2″× 4″missile in ASTM E 1996. Model simulations were made in 2002 with shutters that had impact resistance corresponding to the lighter 2″ × 4″ missile. We include the 2002 Basic results as an interpolation level in the 2008 relativities.

In subsequent studies for the Florida Department of Community Affairs (under funding from the Residential Construction Mitigation Program), we conducted impact tests for both OSB and plywood panels, which are allowable shutter options in the FBC. These wood panel shutters must be fastened to the walls with fasteners specified in the FBC. Two test series were conducted: one for wood-frame walls and the other for masonry walls. These results are documented in DCA reports [ARA (2003) and ARA (2004)].

The following paragraphs discuss the new work on opening protection interpolation and the development of the factors for window leak potential and reinforced concrete roof decks.

We have analyzed how the loss relativities change for opening protection between "none" and "hurricane" by analyzing the relativity tables in the DCA reports. Figure 4-4 plots the average effects for different roof shapes for the weakest, mid, and strongest houses in the 2002 relativity tables. Each point in Figure 4-4 is a vertical column average from the loss relativity tables of 2002. We see that the variation in these averages depends on house strength. However, use of an average interpolation factor simplifies the implementation and is within about 10% of the column-wise averages. The average interpolation factors (S) are given in Table 4-15. These factors are applied according to the following equation:

$$R = R_H + (R_N - R_H) * S \qquad \textit{(4-2)}$$

where R_H is the loss relativity for hurricane opening protection, R_N is the loss relativity for no opening protection, and S is the shutter interpolation factor in Table 4-15. For example, for the weakest house in Terrain C, $R_N = 1.00$ and $R_H = 0.7337$. If this house has plywood shutters installed per the FBC, then the relativity is given by 0.7337 + (1.0 – 0.7337) * 0.46 = 0.856. This interpolation should be performed prior to the application of other secondary factors.

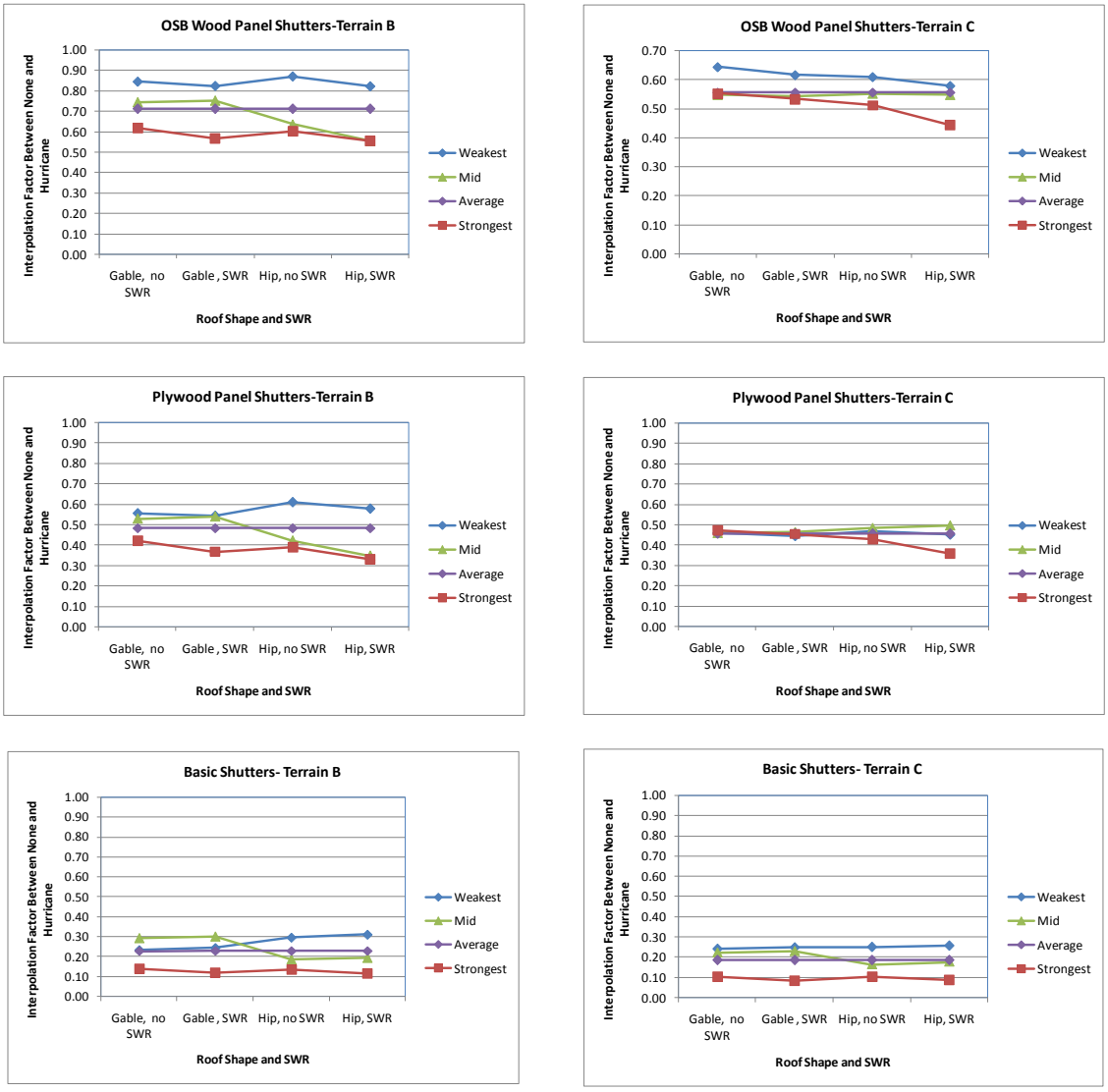


Figure 4-4. Wood Panel and Basic Shutter Interpolation Factors

We include an "Ordinary" shutter in Table 4-15 as part of the OSB level of protection. Ordinary shutters include certain steel, aluminum, and polycarbonate products that are properly installed, but do not meet the current impact/pressure-cycling test standards. Many of these products may have been installed prior to adoption of the current standardized requirements for wind-borne debris impact and hurricane pressure cycle loads. We also recommend that the "Ordinary" shutter designation includes shutters of any style and material that meets the ASCE 7-88 requirement for wind pressure resistance. We map the Ordinary designation to the OSB shutter protection since this is the minimal level of opening protection recognized in this study.[32] These products will provide protection for shingle and other light weight debris

[32] The "Ordinary" protection rating provides credits to homeowners with existing shutter devices that cannot be verified under the more stringent Hurricane or Basic definitions. The Ordinary credit allows for policyholders to receive a credit for devices that will provide some protection. ARA developed the concept of Ordinary shutters as part of a study for Citizens Property Insurance in 2002. Ordinary was mapped to plywood opening protection in earlier studies. However, due to the fact that Ordinary shutters do not have minimal fastening requirements (whereas the fastening requirements for OSB/ Plywood panels are specified in the FBC), we map Ordinary shutters to the weaker OSB category in this study.

as well as provide some rain-screen protection of the openings to reduce the effects of wind-driven rain. The definitions for mitigation features, including Ordinary shutters are given in Appendix A.

Regarding permanently installed opening protection, we do not have enough data on shutter installation frequency to include special factors for impact resistant glazing. This type of protection is always in place and requires no action by the homeowner prior to the storm. However, impact resistant units are also expensive to replace. These units generally have to be totally replaced if the glazing is cracked to the slightest degree by a missile.

Tempered glass has improved impact resistance over annealed glass, but tempered is generally only used for sliding glass doors and other large openings and is generally not present on all openings in a home. Tempered glass was used for the sliding glass doors modeled in this study.

Vinyl Siding (No. 10). Vinyl siding is an exterior wall covering that has been observed to be more vulnerable to failure in windstorms than other types of wall coverings. We apply an engineering judgment factor of 1.02 for houses with vinyl siding wall covers.

Window Leak Potential (No. 11). We ran a matrix of mitigation features for window/door leak potential with an updated water leakage model as described in Section 3.6.1.3. The matrix included 2 window types; 2 levels to cover a range in the number of openings on the house; no opening protection and opening protection; and SWR, no SWR. These simulations were made for a strong 1-story shingle roof cover house with FBC roof cover. The house corresponded to A177G and A178G in Table 2-6. The window types corresponded to Casement/Fixed type windows and Jalousie type windows (Other). Casement windows swing out and tend to seal tighter when subjected to positive pressures. Fixed windows, like a "picture window," do not have any moving parts and hence are inherently less vulnerable to leaking.

The results were compared to the base results to determine the impacts of window/door leakiness on the loss costs. A simplified set of secondary factors were developed and are given in Table 4-15. These factors are applied by counting the number of window types in each category and multiplying the resulting *K* factors together. The effects range up to about 25% for a strong house with a large number of windows and no shutters. These effects are applied to 1-R and hence are proportionally less for weaker houses and will have no effect on the weakest house (R=1). An average effect for the entire table is about 10% for the no shutter case and 8% for shutters. Non-porous shutters help reduce the effects of positive pressure-induced leaks since the shutters act as a rain screen and also slightly reduce the pressure behind the shutter. Non-porous shutters include solid panel shutters that do not allow water leakage through the shutter. Water leakage around the edges of the shutter is expected. No shutters, impact resistant glazing, and porous shutters are treated in the "other" category.

Double-Wrap Roof-to-Wall Connection (No. 12). The roof-to-wall connection is an established part of the mitigation inspections in the state of Florida. Double-wrap roof-to-wall connections were included in the main loss relativity tables in the 2002 study. The loss reduction improvement from a single-wrap to a double-wrap connection is small, but not negligible. Double-wrap strength connectors are needed to satisfy the load requirements of the FBC in many parts of the state.

We performed a sensitivity study on double-wrap roof-to-wall connections. We analyzed the column-wise set of houses with FBC roof covers and Decks B and C for double wrap connectors. We computed the average loss reduction of the double-wrap connectors when compared to the same house with single-wrap connectors. We found that the average loss reduction is greater for houses with no opening protection (these houses are more vulnerable to internal pressures as a result of glazing failures from wind-borne debris). Secondary Factor 12 in Table 4-15 provides the K_i factors for double wrap connectors. These factors are applied to the loss relativity table look-up for the single wrap version of the house. For example, for a Terrain C two story FBC tile hip roof house with 7:12 roof slope, no SWR,

wood soffits, Deck C, and no shutters, we find in Table 4-12 that the loss relativity = 0.2408. From Table 4-15, we apply K_i = 0.93 and we compute R' = 0.2279 using Equation (4-1).

This factor is not applied to post-FBC construction since the roof-to-wall strength was part of the modeled design strength.

Roof Cover Age (No. 13). Roof covers age and deteriorate over time. The extent of aging depends on the roof cover materials, quality of installation, roof slope and complexity, roof exposure to sun, shading from other buildings or trees, thermal cycling, color, roof deck stability, and attic ventilation. It is therefore likely that sections of the same roof will age at different rates. Proper installation and maintenance is critical to assure the maximum performance of all roof covers over time. Nevertheless, roof covers do age and lose a portion of their newly-installed wind resistance over time.

Shingles become brittle, adhesives dry out, granules break away, surface cracks appear, and curling at the edges may occur. Blisters may also develop as the shingles age. Walking on a shingle roof can also induce scuffs and loss of granules thus accelerating deterioration of the surface. These processes occur naturally due to UV radiation, heating-cooling cycles, rain, humidity, retained moisture, and other factors. Rubber and bituminous-type materials, such as membrane roofs and built-up roofs, also deteriorate due to these effects.

Tile roof covers are subject to the same environmental conditions, but generally age at a slower pace due to the differences in the materials. The moisture content of the tiles change during dry and wet periods and they expand and contract under normal heating and cooling cycles. Tiles may be set in mortar or foam adhesive or they may be mechanically attached to the roof deck with screws or nails. If the tile is mechanically fastened and the fastener is driven too tight, the tile may crack as the roof flexes. If the fastener is too loose, the tile may crack or lift up every time a wind load is applied. As mortar and foam age, these materials are also more prone to cracking and loss of adhesion. Walking on tile roofs can also induce cracking and breaking. Certain crack patterns in tile roofs can be easily identified as not caused by wind damage.

Moss and other organic growth on tile (including mortar) and wood shake roofs can reduce the life of the roof cover as a result of water retention and/or root infiltration. Wood shakes tend to split, cup, and curl with age.

Metal roof systems may experience fatigue of the fastening system from thermal cycling and, possibly, wind loads. Corrosion may also weaken the metal fastening system.

We introduce a secondary factor to treat roof cover age in an attempt to fairly adjust the loss relativities from new FBC roof covers to non-FBC roof covers. In the absence of a separate research effort on the issue of roof cover aging and how the loss relativities should be adjusted, we recommend the following approach:

1. Roof cover aging factor only applies to FBC roof covers installed per the 2001 FBC and later editions of the code. These roof covers receive the rate differentials associated with FBC roof covers in Table 4-9 through Table 4-12.
2. FBC roof cover age is determined as the difference between the year the roof cover was installed and the current year.
3. The loss relativity for an FBC roof cover is adjusted according to the following steps:
    a. If the FBC roof cover is 5 years or less in age, no adjustment to the loss relativity is applied.
    b. If the roof cover material is a bituminous-based product (shingles, membrane, built-up roof) or a wood-based product, the age factor is based on a 15 year period (A) to transition from the FBC to a non-FBC roof cover.

c. If the roof cover material is cement, clay, slate, metal or any other non-bituminous or wood-based material, the age factor is based on a 20 year period (A) to transition from an FBC to a non-FBC roof cover.
d. The secondary factor to transition from an FBC to a non-FBC roof cover is computed as follows:
    i. Interpolate the loss relativity from the FBC to the non-FBC roof cover using the equations

$$\Delta = R_{non\text{-}FBC} - R_{FBC} \qquad \textit{(4-3a)}$$

$$R = R_{FBC} + \Delta*(N-5)/(A-5)\ ,\ 5 < N < A \qquad \textit{(4-3b)}$$

where Δ = age effect, R_{FBC} and $R_{non\text{-}FBC}$ denote the relativities for the building with FBC and non-FBC roof covers, N = FBC roof cover age in years, and A = FBC to non-FBC transition period (A = 20 for tile, cement, slate, metal and A = 15 for all other materials). For post-FBC construction, if SWR is present, apply the SWR factors directly to the $R_{non\text{-}FBC}$ and R_{FBC} in the above equation. For pre-FBC construction, the look-up values of R should include the SWR value, if SWR is present.

    ii. For $N \leq 5$, $R = R_{FBC.}$
    iii. For $N \geq A$, $R = R_{non\text{-}FBC}$

The Δ value must be determined by looking up two relativities in the loss relativity tables. As an example, consider a non-tile roof cover for the "Mid house," which has a non-FBC roof cover relativity of 0.3091 and an FBC roof cover relativity of 0.1938. If the FBC roof cover is 5 years or less in age, the relativity remains 0.1938. As the FBC-roof reaches 10 years in age, the relativity is calculated by R = 0.1938 + (0.3091- 0.1938)*(10-5)/(15-5) = 0.2515. At 15 years, R = 0.3091. A plot of the change in relativity for this house is given in Figure 4-5 for both shingle (other) and tile roof covers. The relativity increases with age until the non-FBC relativity is attained. Larger relativities mean smaller reductions in wind premium.

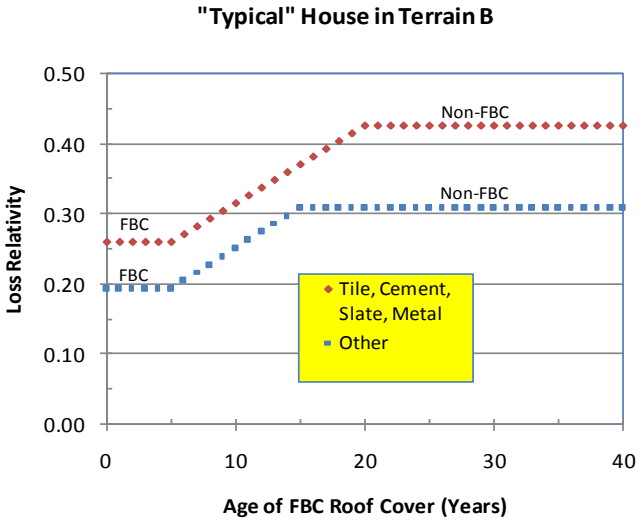


Figure 4-5. Example Roof Cover Age Adjustment to Loss Relativities

We note that the transition periods of 15 and 20 years should not be associated with the assumed life of the roof cover. These transition periods are simply the periods of time for the roof cover to degrade from a new roof cover to an aged, non-FBC roof cover with less wind resistance (and typically a higher threshold for total replacement vs. repair from windstorm-induced damage). The non-FBC roof cover

condition remains a fully functional roof cover. It just doesn't qualify for as much credit as a newer roof cover, which is consistent with insurance claims and damage surveys. Thus, the total life of these roof covers is expected to be more than simply the estimated aging transition period from FBC to non-FBC. Total lifetimes of 25 to 30 years and 40 to 50 years are feasible for these two categories of roof covers ("other" and tile, cement, slate, or metal, respectively). Total lifetimes are not part of any assumption in the modeling of roof cover as FBC and non-FBC in this report.

The total functional lifetime of a roof cover is related to roof cover condition and performance. All roof covers must be maintained and at some point a total replacement is required. As discussed in Section4.2.4.1, roof cover is a wind mitigation component that must be maintained in good condition for the loss relativity tables to be applicable. Hence, a second part of the issue of roof cover aging is whether or not the roof cover meets minimal conditions of performance and repair. This condition requirement is separate from the roof cover age determination. Thus, roof cover age does not mean that the roof cover condition is assumed to remain in good condition for the assumed FBC to non-FBC age transition periods. These age transition periods are assumed to be generally favorable from the home-owners perspective.[33] If either an FBC or non-FBC roof cover is in poor condition, then, as mentioned previously, our recommendation is that the building should not qualify for any wind mitigation rate differentials until the condition of the roof cover is improved, generally by installing a new roof cover.

4.3 Post-FBC Construction

Wind loading provisions of the Florida Building Code (FBC) and effective dates of FBC code changes were summarized in Section 2.2.3. Two FBC construction eras were identified for the purposes of developing loss relativities for wind mitigation features:

1. FBC 2001 includes permit application dates of March 1, 2002 through December 7, 2006.
2. FBC 2006 includes permit applications on or after December 8, 2006.

There are several methods by which the FBC era can be determined and these are discussed in Section 2.2.4.8. There are many code amendments between these dates. The FBC 2006 date is significant since ring shank nails, soffit loads, Panhandle WBD region, and 150 mph shingles were all introduced at that time. We designed buildings to the 2006 FBC and used our previous designs from the 2002 loss relativity study for the FBC 2001 designs. Appendix D summarized the 2006 FBC design calculations.

Section 4.3.1 contains the 2006 FBC loss relativities and Section 4.3.2 contains the 2001 FBC loss relativities.

4.3.1 2006 FBC Construction

We developed new designs for each Florida wind zone from 100 to 150 mph, including the HVHZ locations. We used a single point in each wind zone (the first point in Table 2-4). At each wind zone point, we also simulated the strongest and weakest house from the pre-FBC tables. These values were used to compress the post-FBC relativities consistent with the pre-FBC relativities.

Consistency Checks with Single Statewide Pre-FBC Relativities. The resulting relativities were compared to the pre-FBC relativities by mapping the 2006 FBC design features to the closest row in the pre-FBC relativity tables. This comparison was done to determine if the wind-zone specific 2006 FBC tables would be "reasonably consistent" with the pre-FBC (non wind-zone specific) tables. By "mapping

[33] The transition from FBC to non-FBC means that the additional resistance from hurricane damage and loss is transitioning from a properly installed brand new roof cover to a roof cover that is still in good and repairable condition, but it is simply not as resistive to wind damage as a brand new roof cover. The non-FBC roof cover designation in the loss relativity tables applies to good condition roof covers.

the post-FBC designs," we mean that the post-FBC designs were located in a consistent row with the pre-FBC tables (Table 4-9 through Table 4-12). That pre-FBC row was then used to map the pre-FBC statewide relativity to the post-FBC specific wind-zone relativity. For example, if the post-FBC design consisted of FBC roof cover, Wrap Roof-to-Wall Connection, Roof Deck C, Hurricane Protection, and Wood Soffits, then those specific features from the pre-FBC tables were used in the mapping.

This consistency analysis provides a direct way to judge how much error is introduced by adjusting the post-FBC windzone-dependent design relativities to match the pre-FBC tables. If the post-FBC relativities are not consistent with the pre-FBC relativities for similar house mitigation features, then the final rate differentials will not be robust for both pre- and post-FBC construction.

Figure 4-6 shows the results of these mappings for Terrains B and C. These plots are similar in concept to those in Figure 4-1, which illustrated some of the errors introduced in using a single statewide table for pre-FBC construction. The deviation from the 45-degree line is a measure of the error in relativity for 2006 FBC construction when the post-FBC design features are located within the single statewide pre-FBC table. We see that there are some notable errors introduced for low windspeed zones. The low-wind-zone relativity errors approach 40% as the maximum error for the locations analyzed. The errors are less for higher windspeed zones. For 130 mph and higher in Terrain B and for 120 mph and higher in Terrain C, the errors are generally small (average error less is than about 5%).[34]

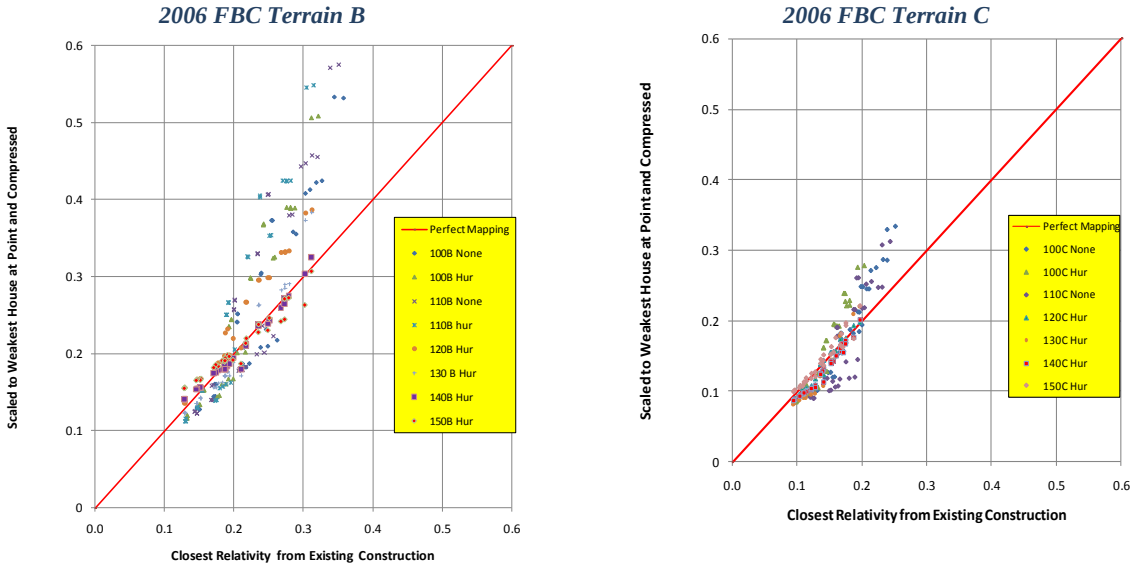


Figure 4-6. FBC 2006 Loss Relativities Normalized by Wind Zone vs. pre-FBC Statewide Relativity

FBC 2006 Loss Relativities. The loss relativities for new single family houses built to the 2006 FBC are given in Table 4-17 and Table 4-18 for Terrains B and C, respectively. These relativities reflect the consistency constraint of mapping the building features into the pre-FBC statewide relativities. These relativities match the strongest features of the pre-FBC tables and the lowest relativities are slightly lower than the lowest relativity in Table 4-9 through Table 4-12.

[34] These results are similar to those in Section 4.2.3 in that the loss costs in lower-wind hazard locations will tend to ameliorate the errors in dollar terms (somewhat) regarding wind mitigation rate differentials. However, we recommend that regionalization of the relativities be completed as soon as possible to produce the best possible wind mitigation rate differentials and uniform grading scale for homes throughout the state.

Table 4-17. Terrain B 2006 FBC Single Family[1]

Terrain B FBC 2006 Single Family[2]			Low Roof Slope (≤ 5:12)								Other Roof Slope (≥ 6:12)							
			Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile		Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[3]	100	None	0.2622	0.2222	0.1745	0.1480	0.3577	0.3095	0.2555	0.2054	0.2488	0.2173	0.1730	0.1506	0.3267	0.2895	0.2394	0.2048
		Hurricane[5]	0.2168	0.1887	0.1575	0.1333	0.3215	0.2816	0.2430	0.1967	0.1993	0.1794	0.1515	0.1331	0.2879	0.2589	0.2248	0.1934
	110	None	0.2570	0.2178	0.1710	0.1450	0.3505	0.3033	0.2504	0.2013	0.2438	0.2130	0.1695	0.1476	0.3202	0.2837	0.2346	0.2007
		Hurricane[6]	0.2125	0.1849	0.1544	0.1306	0.3151	0.2760	0.2381	0.1928	0.1953	0.1758	0.1485	0.1304	0.2821	0.2537	0.2203	0.1895
	≥ 120	None[7]	0.2544	0.2156	0.1693	0.1436	0.3470	0.3003	0.2479	0.1993	0.2414	0.2108	0.1678	0.1461	0.3170	0.1809	0.2323	0.1987
		Hurricane	0.2103	0.1831	0.1528	0.1293	0.3119	0.2732	0.2358	0.1908	0.1934	0.1741	0.1470	0.1291	0.2793	0.2512	0.2181	0.1876
Non-FBC[4]	100	None	0.4709	0.3925	0.2895	0.2278	0.5950	0.5070	0.4202	0.3167	0.4213	0.3530	0.2709	0.2270	0.5177	0.4512	0.3720	0.3108
		Hurricane	0.4146	0.3475	0.2727	0.2161	0.5502	0.4682	0.4068	0.3079	0.3577	0.3034	0.2492	0.2109	0.4654	0.4127	0.3542	0.2953
	110	None	0.4615	0.3847	0.2837	0.2232	0.5831	0.4969	0.4118	0.3104	0.4129	0.3459	0.2655	0.2225	0.5073	0.4422	0.3646	0.3046
		Hurricane	0.4063	0.3406	0.2672	0.2118	0.5392	0.4588	0.3987	0.3017	0.3505	0.2973	0.2442	0.2067	0.4561	0.4044	0.3471	0.2894
	≥ 120	None	0.4569	0.3808	0.2809	0.2210	0.5773	0.4919	0.4077	0.3073	0.4087	0.3425	0.2628	0.2202	0.5023	0.4378	0.3609	0.3015
		Hurricane	0.4022	0.3371	0.2646	0.2097	0.5338	0.4542	0.3947	0.2987	0.3470	0.2944	0.2418	0.2046	0.4515	0.4004	0.3436	0.2865

[1] Refer to discussion in Section 2.2.4.8 and Figure 4-7 to determine whether or not FBC 2001 or FBC 2006 relativity tables should be used for FBC 2006 construction.
[2] Use Table 4-16 for FBC 2006 houses with reinforced concrete roof deck.
[3] FBC Roof Covers (apply this part of the table with no roof cover age interpolation for 2006 FBC roof covers less than or equal to 5 years old).
[4] Non FBC Roof Covers (this part of the table is used with FBC Roof Covers to interpolate for 2006 FBC construction with roof covers 6 years old or more). See Section 4.2.5.
[5] Opening Protection is not required by the 2006 FBC for 100 mph design windspeeds. Hence, this row only applies to 2006 FBC homes that are further mitigated with opening protection.
[6] Opening protection is required within 1 mile of coast for 110 mph design windspeeds. For most locations in Florida in the 110 mph windzone, this row only applies to 2006 FBC homes mitigated with opening protection.
[7] This row is included only for interpolation of shutters less than "Hurricane" level of protection per Table 4-15.

Table 4-18. Terrain C 2006 FBC Single Family[1]

Terrain C FBC 2006 Single Family[2]			Low Roof Slope (≤ 5:12)								Other Roof Slope (≥ 6:12)							
			Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile		Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[3]	100	None	0.2923	0.2141	0.1816	0.1316	0.3104	0.2558	0.2157	0.1698	0.2677	0.2053	0.1848	0.1357	0.2844	0.2408	0.2087	0.1701
		Hurricane[5]	0.1449	0.1256	0.1136	0.0991	0.2027	0.1802	0.1733	0.1448	0.1314	0.1170	0.1076	0.0976	0.1803	0.1640	0.1571	0.1402
	110	None	0.2836	0.2077	0.1762	0.1277	0.3012	0.2482	0.2093	0.1647	0.2597	0.1992	0.1793	0.1317	0.2759	0.2336	0.2025	0.1650
		Hurricane[6]	0.1406	0.1219	0.1102	0.0961	0.1967	0.1748	0.1681	0.1405	0.1275	0.1135	0.1044	0.0947	0.1749	0.1591	0.1524	0.1360
	≥ 120	None[7]	0.2836	0.2077	0.1762	0.1277	0.3012	0.2482	0.2093	0.1647	0.2597	0.1992	0.1793	0.1317	0.2759	0.2336	0.2025	0.1650
		Hurricane	0.1406	0.1219	0.1102	0.0961	0.1967	0.1748	0.1681	0.1405	0.1275	0.1135	0.1044	0.0947	0.1749	0.1591	0.1524	0.1360
	HVHZ[8]	Hurricane	0.1350	0.1170	0.1058	0.0923	0.1888	0.1678	0.1614	0.1349	0.1224	0.1090	0.1002	0.0909	0.1679	0.1527	0.1463	0.1306
Non-FBC[4]	100	None	0.4350	0.3496	0.2586	0.1952	0.4680	0.4008	0.3340	0.2633	0.3808	0.3071	0.2500	0.1930	0.4096	0.3562	0.3049	0.2555
		Hurricane	0.2660	0.2259	0.1864	0.1555	0.3376	0.2992	0.2861	0.2330	0.2221	0.1909	0.1678	0.1481	0.2863	0.2604	0.2483	0.2213
	110	None	0.4220	0.3392	0.2509	0.1894	0.4541	0.3889	0.3240	0.2555	0.3695	0.2979	0.2426	0.1872	0.3974	0.3456	0.2958	0.2479
		Hurricane	0.2581	0.2192	0.1808	0.1509	0.3275	0.2903	0.2776	0.2261	0.2155	0.1852	0.1628	0.1437	0.2778	0.2526	0.2409	0.2147
	≥ 120	None	0.4220	0.3392	0.2509	0.1894	0.4541	0.3889	0.3240	0.2555	0.3695	0.2979	0.2426	0.1872	0.3974	0.3456	0.2958	0.2479
		Hurricane	0.2581	0.2192	0.1808	0.1509	0.3275	0.2903	0.2776	0.2261	0.2155	0.1852	0.1628	0.1437	0.2778	0.2526	0.2409	0.2147
	HVHZ	Hurricane	0.2478	0.2104	0.1736	0.1448	0.3144	0.2787	0.2665	0.2170	0.2069	0.1778	0.1563	0.1379	0.2667	0.2425	0.2313	0.2061

[1] Refer to discussion in Section 2.2.4.8 and Figure 4-7 to determine whether or not FBC 2001 or FBC 2006 relativity tables should be used for FBC 2006 construction.
[2] Use Table 4-16 for FBC 2006 houses with reinforced concrete roof deck.
[3] FBC Roof Covers (apply this part of the table with no roof cover age interpolation for 2006 FBC roof covers less than or equal to 5 years old).
[4] Non FBC Roof Covers (this part of the table is used with FBC Roof Covers to interpolate for 2006 FBC construction with roof covers 6 years old or more). See Section 4.2.5.
[5] Opening Protection is not required by the 2006 FBC for 100 mph design windspeeds. Hence, this row only applies to 2006 FBC homes that are further mitigated with opening protection.
[6] Opening protection is required within 1 mile of coast for 110 mph design windspeeds. For most locations in Florida in the 110 mph windzone, this row only applies to 2006 FBC homes mitigated with opening protection.
[7] This row is included only for interpolation of shutters less than "Hurricane" level of protection per Table 4-15.
[8] Secondary Factor 4 (All Openings Protected) has already been considered for HVHZ.

These tables have both FBC roof cover and non-FBC roof cover relativities. The non-FBC roof cover relativities are used for roof cover age interpolation. In addition, the tables have relativities for no opening protection for ≥ 120 mph wind zones. These relativities are provided to allow for shutter interpolation, if needed, per Secondary Factor No. 9 in Table 4-15.

As discussed in Section2.2.4.8, the 2006 FBC included several important changes in terms of wind mitigation (soffit design loads, ring-shank deck nails, 150 mph shingles). There are also acceptable alternatives in the FBC 2006 regarding the use of ring-shank nails and 150 mph shingles. As a practical matter, we decided to model the FBC 2006 single family residences with ring-shank nails and with the 150 mph shingle for ≥ 130 mph wind zones. This approach produces the greatest change from FBC 2001.Fewer changes would produce results very similar to FBC 2001. Based on the modeling approach we adopted for FBC 2006, we recommend that users apply the decision tree in Figure 4-7 to determine whether to apply the FBC 2001 tables or the FBC 2006 tables to post-FBC single family and Group I multi-family residences. This logic is consistent with the discussion in Section 2.2.4.8.

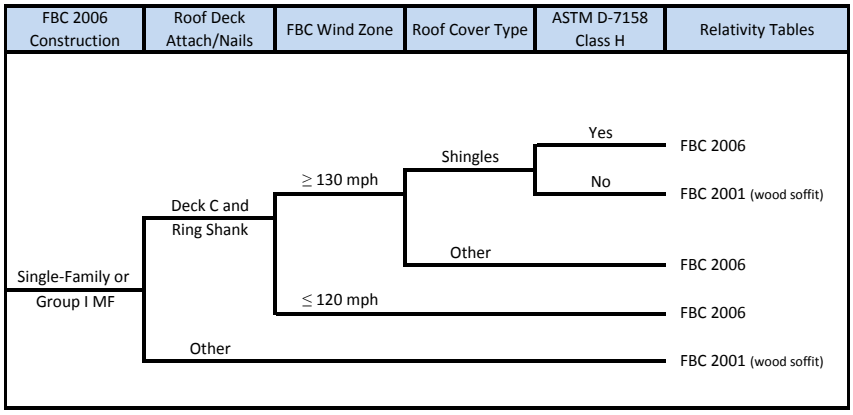


Figure 4-7. Determination of Appropriate Relativity Tables for FBC 2006 Single Family and Multi-family Group I Construction

For residences with reinforced concrete roof decks, Table 4-16 should be applied for post-FBC construction. Note that secondary Factor No. 4 should be applied to the values in Table 4-16 if the residence is located in the HVHZ.

Secondary Factors Regarding secondary factors for FBC 2006 construction, the following notes apply:

1. Factor 1 or Factor 8 can be applied if the wood deck is dimensional lumber or enhanced (See Appendix A).
2. Factor 3 applies to the FBC homes with reinforced masonry walls.
3. The HVHZ relativities reflect the fact that all openings are protected and, hence, there is no need to apply Secondary Factor 4 to the HVHZ results to Table 4-17 and Table 4-18. Secondary Factor 4 should be applied to non-HVHZ locations if all openings are protected to "Hurricane" level.
4. If the opening protection is provided by wood panel shutters, use the interpolation approach given by Equation (4-2) and the factors (Secondary Factor 9) in Table 4-15.
5. If the house has vinyl siding, apply Secondary Factor 10 in Table 4-15.
6. The leak potential factor (Secondary Factor 11 in Table 4-15) for windows, doors, and skylights should be applied to post-FBC houses.
7. The double-wrap (roof-to-wall) connection factor is not applicable to post-FBC construction.
8. Roof cover age interpolation is appropriate for post-FBC.
9. If the house has a reinforced concrete roof deck, do not use Table 4-17 or Table 4-18. Use Table 4-16 instead.
10. If the house has Secondary Water Resistance (SWR), which meets the requirements in Appendix A, apply the appropriate factor from Table 4-19 or Table 4-20. We note that few FBC houses are built with self-adhering SWR and, hence, this factor will rarely be applied to post-FBC residences.

All secondary factors are applied using Equation (4-1). For example, for an FBC 2006 two-story shingle house in 130 mph Terrain B wind zone with low roof slope and gable roof, the loss relativity is 0.1528. This house does not have SWR and, hence, Table 4-19 does not apply. The opening protection is provided by non-porous shutters. It has 20 double hung windows and 2 sliding glass doors. According to Table 4-15, the opening count is 28 and the k_i factor is 1.08. The adjusted loss relativity according to Equation (4-4) is given by

$$R' = 0.1528(1.08)^{(1-0.1528)} = 0.164 \qquad \textit{(4-4)}$$

which corresponds to a 7% increase in *R*.

We note that the window leakiness factor applies to all buildings, pre- and post-FBC.

4.3.2 FBC 2001 Loss Relativities

The FBC 2001 loss relativities were developed by simulating the FBC 2001 designs developed in the 2002 loss relativity study to the updated hurricane wind hazard model results summarized in Section 2.3.6.

These results were also checked for consistency similar to the FBC 2006 designs. The conclusions are similar in that the largest errors occur in the lowest wind zone locations. The use of a single statewide table for pre-FBC construction and the location of the FBC 2001 designs in those tables produces the errors as illustrated in Figure 4-8.

Table 4-21 and Table 4-22 contain the loss relativities for houses built to the FBC 2001. Table 4-23 and Table 4-24 contain the SWR secondary factors for these homes. The application of these factors and other secondary factors follows the same approach as illustrated for FBC 2006. Since the FBC 2001 did not include requirements for soffit design pressures, the FBC 2001 tables include wood and other soffits. The determination of soffit material is straightforward and the verification issues are discussed in Appendix A.

We note that the FBC tables and the SWR tables contain all the information needed for mitigation factors (for designs beyond the FBC minimal requirements) for opening protection and applying SWR. For example, if shutters are applied to a FBC 2001 house (1 story, tile, high roof slope, wood soffits) in a 110 mph Terrain B location, the loss relativity from Table 4-21 changes from 0.2650 to 0.2309, which corresponds to about a 13% reduction.

FBC 2001 Partially-Enclosed Designs. The 2001 FBC allowed for partially-enclosed designs in the WBD region. Partially enclosed designs do not provide opening protection for wind-borne debris. Although the building is designed for internal pressures, it still has unprotected glazing and hence is subject to higher losses than a building with opening protection.

The relativities for partially-enclosed designs are determined by using the no opening protection values in Table 4-21 and Table 4-22 with a secondary factor of 0.98. This factor accounts for the increased pressure resistance of the windows, doors, and other components due to the internal pressure design requirement.

Partially enclosed designs are not allowed in the HVHZ and, hence, these factors do not apply to the HVHZ.

Consideration of 2001 Panhandle WBD Region Exemption. The 2001 FBC had an exemption for the Florida Panhandle for WBD requirements for buildings more than one mile from the coast. Therefore, houses built in the Panhandle to the 2001 FBC more than 1 mile from the coast and in a $\geq$ 120 mph wind zone may not have WBD protection. The loss relativities for these houses should be determined by using the no shutter results for homes built without opening protection under the Panhandle WBD exception.

Secondary Factors. Refer to the notes in Section 4.3.1 for discussion of applicable Secondary Factors for FBC 2001 construction. Note that Secondary Factor No. 14 may be applicable to FBC 2001 construction.

Table 4-19. Terrain B Secondary Water Resistance Factors for 2006 FBC

Terrain B FBC 2006 Single Family SWR Factors[1]			Low Roof Slope (≤ 5:12)								Other Roof Slope (≥ 6:12)							
			Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile		Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100, 110	None	0.940	0.956	0.980	0.980	0.963	0.979	0.980	0.980	0.958	0.974	0.980	0.980	0.975	0.980	0.980	0.980
	≥ 120	Hurricane	0.946	0.971	0.980	0.980	0.969	0.980	0.980	0.980	0.966	0.980	0.980	0.980	0.978	0.980	0.980	0.980
Non-FBC[3]	100, 110	None	0.736	0.769	0.920	0.959	0.844	0.877	0.961	0.979	0.772	0.830	0.928	0.959	0.872	0.917	0.968	0.980
	≥ 120	Hurricane	0.737	0.792	0.925	0.963	0.857	0.894	0.968	0.980	0.786	0.855	0.935	0.971	0.884	0.925	0.973	0.980

[1] These SWR factors must be determined by separate inspection or affadavit. SWR is not required by the FBC and is not typical of new construction.

[2] FBC roof covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

[3] Non-FBC roof covers (this part of the table is used with FBC to interpolate for 2001 FBC construction with roof covers 6 years old or more). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

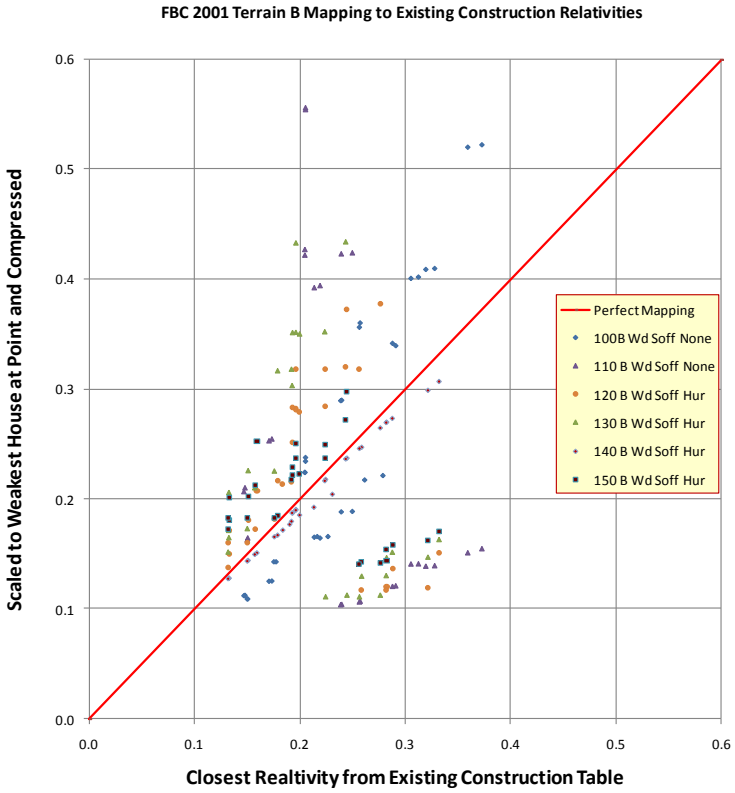
Table 4-20. Terrain C Secondary Water Resistance Factors for 2006 FBC

Terrain C FBC 2006 Single Family SWR Factors[1]			Low Roof Slope (≤ 5:12)								Other Roof Slope (≥ 6:12)							
			Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile		Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100, 110	None	0.939	0.925	0.976	0.980	0.949	0.954	0.980	0.980	0.958	0.963	0.979	0.980	0.969	0.978	0.980	0.980
	≥ 120	Hurricane	0.910	0.938	0.980	0.980	0.950	0.963	0.980	0.980	0.951	0.972	0.980	0.980	0.973	0.979	0.980	0.980
Non-FBC[3]	100, 110	None	0.735	0.693	0.879	0.889	0.803	0.809	0.929	0.951	0.785	0.777	0.904	0.913	0.852	0.875	0.946	0.964
	≥ 120	Hurricane	0.668	0.721	0.869	0.915	0.809	0.846	0.936	0.962	0.752	0.815	0.903	0.941	0.864	0.900	0.954	0.974

[1] These SWR factors must be determined by separate inspection or affadavit. SWR is not required by the FBC and is not typical of new construction.

[2] FBC roof covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

[3] Non-FBC roof covers (this part of the table is used with FBC to interpolate for 2001 FBC construction with roof covers 6 years old or more). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).



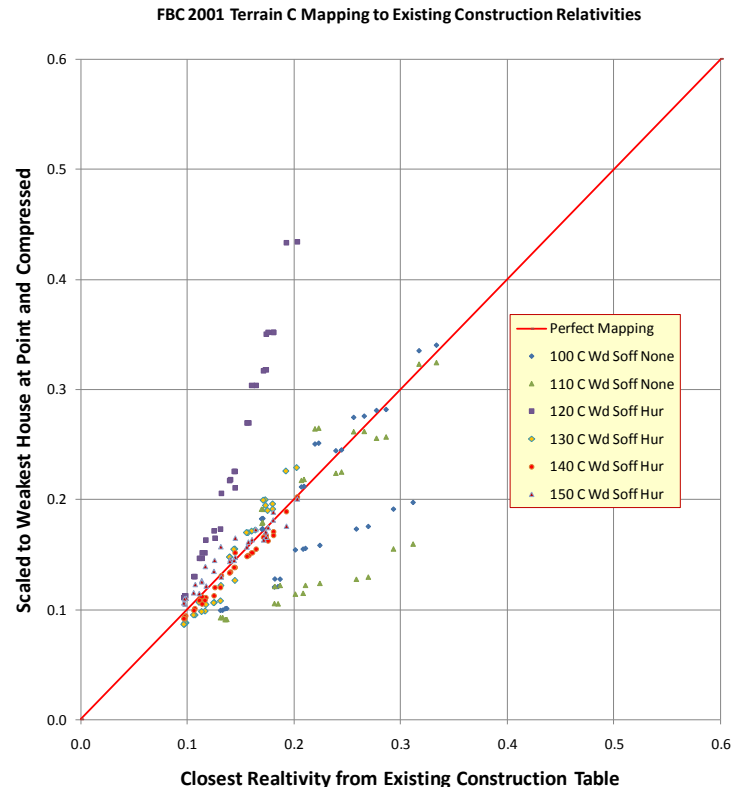


Figure 4-8. FBC 2001 Loss Relativities Normalized by Wind Zone vs. pre-FBC Statewide Relativity

Table 4-21. Terrain B 2001 FBC Single Family

Terrain B 2001 FBC Single Family[1]				Low Roof Slope (≤ 5:12)								Other Roof Slope (≥ 6:12)							
				Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile		Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Soffits[7]	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100,110	None	Other	0.3186	0.2559	0.1937	0.1599	0.4103	0.3389	0.2720	0.2155	0.3027	0.2554	0.2021	0.1674	0.3752	0.3231	0.2650	0.2183
			Wood	0.2788	0.2267	0.1775	0.1480	0.3727	0.3125	0.2572	0.2054	0.2498	0.2192	0.1735	0.1506	0.3279	0.2910	0.2397	0.2048
		Hurricane[4, 5]	Other	0.2539	0.2050	0.1654	0.1365	0.3518	0.2953	0.2496	0.1995	0.2290	0.1974	0.1603	0.1376	0.3122	0.2744	0.2309	0.1968
			Wood	0.2312	0.1908	0.1598	0.1333	0.3321	0.2825	0.2450	0.1967	0.2002	0.1794	0.1515	0.1331	0.2879	0.2589	0.2248	0.1935
	≥ 120	None[6]	Other	0.3154	0.2533	0.1918	0.1583	0.4062	0.3355	0.2693	0.2133	0.2997	0.2528	0.2001	0.1657	0.3714	0.3199	0.2624	0.2161
			Wood	0.2760	0.2244	0.1757	0.1465	0.3690	0.3094	0.2546	0.2033	0.2473	0.2170	0.1718	0.1491	0.3246	0.2881	0.2373	0.2028
		Hurricane	Other	0.2514	0.2030	0.1637	0.1351	0.3483	0.2923	0.2471	0.1975	0.2267	0.1954	0.1587	0.1362	0.3091	0.2717	0.2286	0.1948
			Wood	0.2289	0.1889	0.1582	0.1320	0.3288	0.2797	0.2426	0.1947	0.1982	0.1776	0.1500	0.1318	0.2850	0.2563	0.2226	0.1916
Non-FBC[3]	100,110	None	Other	0.5531	0.4345	0.3147	0.2422	0.6640	0.5415	0.4417	0.3293	0.4844	0.3955	0.3042	0.2457	0.5726	0.4895	0.4012	0.3266
			Wood	0.4984	0.3979	0.2942	0.2286	0.6168	0.5109	0.4248	0.3176	0.4227	0.3530	0.2716	0.2273	0.5183	0.4532	0.3732	0.3108
		Hurricane	Other	0.4728	0.3709	0.2839	0.2209	0.5968	0.4874	0.4159	0.3116	0.3990	0.3285	0.2612	0.2172	0.4994	0.4333	0.3641	0.3008
			Wood	0.4370	0.3490	0.2765	0.2161	0.5683	0.4703	0.4094	0.3079	0.3592	0.3045	0.2497	0.2109	0.4667	0.4138	0.3546	0.2953
	≥ 120	None	Other	0.5476	0.4302	0.3116	0.2398	0.6574	0.5361	0.4373	0.3260	0.4796	0.3915	0.3012	0.2432	0.5669	0.4846	0.3972	0.3233
			Wood	0.4934	0.3939	0.2913	0.2263	0.6106	0.5058	0.4206	0.3144	0.4185	0.3495	0.2689	0.2250	0.5131	0.4487	0.3695	0.3077
		Hurricane	Other	0.4681	0.3672	0.2811	0.2187	0.5908	0.4825	0.4117	0.3085	0.3950	0.3252	0.2586	0.2150	0.4944	0.4290	0.3605	0.2978
			Wood	0.4326	0.3455	0.2737	0.2139	0.5626	0.4656	0.4053	0.3048	0.3556	0.3015	0.2472	0.2088	0.4620	0.4097	0.3511	0.2923

[1] Use Table 4-16 for FBC 2001 houses with reinforced concrete roof deck.

[2] FBC Roof Covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old).

[3] Non FBC Roof Covers (this part of the table is used with FBC Roof Covers to interpolate for 2001 FBC construction with roof covers 6 years old or more). See Section 4.2.5.

[4] Opening Protection is not required by the 2001 FBC for 100 mph design windspeeds. Hence, this row only applies to 2001 FBC homes that are further mitigated with opening protection.

[5] Opening protection is required within 1 mile of coast for 110 mph design windspeeds. For most locations in Florida in the 110 mph windzone, this row only applies to 2001 FBC homes mitigated with opening protection.

[6] This row included for: (a) Panhandle WBD exception; (b) interpolation of shutters less than "Hurricane" per Table 4-15; and (c) partially enclosed designs in the WBDR. Apply a factor of 0.98 to this row for partially enclosed designs, per Table 4-15.

[7] Use wood soffit row for the use of this table for any FBC 2006 construction.

Table 4-22. Terrain C 2001 FBC Single Family

Terrain C 2001 FBC Single Family[1]				Low Roof Slope (≤ 5:12)								Other Roof Slope (≥ 6:12)							
				Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile		Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Soffits[7]	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100,110	None	Other	0.3742	0.2781	0.2333	0.1756	0.3956	0.3150	0.2688	0.2083	0.3398	0.2673	0.2494	0.1878	0.3543	0.2969	0.2706	0.2148
			Wood	0.3117	0.2243	0.1870	0.1331	0.3336	0.2659	0.2232	0.1709	0.2697	0.2086	0.1851	0.1370	0.2864	0.2446	0.2094	0.1706
		Hurricane[4, 5]	Other	0.2249	0.1747	0.1581	0.1272	0.2732	0.2245	0.2080	0.1685	0.1966	0.1692	0.1576	0.1307	0.2393	0.2106	0.1960	0.1684
			Wood	0.1616	0.1283	0.1180	0.0993	0.2147	0.1823	0.1763	0.1452	0.1324	0.1174	0.1081	0.0978	0.1806	0.1643	0.1571	0.1403
	≥ 120	None[6]	Other	0.3450	0.2650	0.2207	0.1725	0.3633	0.3016	0.2548	0.2051	0.3345	0.2618	0.2464	0.1854	0.3485	0.2907	0.2672	0.2125
			Wood	0.2894	0.2120	0.1798	0.1303	0.3073	0.2532	0.2135	0.1681	0.2650	0.2032	0.1830	0.1343	0.2816	0.2384	0.2066	0.1684
		Hurricane	Other	0.1974	0.1696	0.1497	0.1250	0.2483	0.2190	0.1987	0.1661	0.1931	0.1668	0.1555	0.1292	0.2358	0.2081	0.1933	0.1660
			Wood	0.1435	0.1243	0.1125	0.0981	0.2007	0.1784	0.1716	0.1434	0.1301	0.1158	0.1065	0.0966	0.1785	0.1624	0.1555	0.1388
	HVHZ[8]	Hurricane	Other	0.1935	0.1662	0.1467	0.1225	0.2433	0.2146	0.1947	0.1628	0.1892	0.1635	0.1524	0.1266	0.2311	0.2039	0.1895	0.1627
			Wood	0.1406	0.1219	0.1102	0.0961	0.1967	0.1748	0.1681	0.1405	0.1275	0.1135	0.1044	0.0947	0.1749	0.1591	0.1524	0.1360
Non-FBC[3]	100,110	None	Other	0.5406	0.4252	0.3280	0.2466	0.5696	0.4679	0.3988	0.3077	0.4634	0.3738	0.3270	0.2503	0.4879	0.4167	0.3753	0.3056
			Wood	0.4582	0.3597	0.2680	0.1970	0.4958	0.4103	0.3439	0.2653	0.3815	0.3105	0.2507	0.1936	0.4125	0.3594	0.3053	0.2570
		Hurricane	Other	0.3816	0.2980	0.2443	0.1917	0.4364	0.3576	0.3307	0.2625	0.3089	0.2573	0.2276	0.1876	0.3596	0.3166	0.2950	0.2548
			Wood	0.2928	0.2295	0.1942	0.1557	0.3606	0.3017	0.2915	0.2333	0.2239	0.1926	0.1683	0.1481	0.2871	0.2609	0.2489	0.2218
	≥ 120	None	Other	0.5072	0.4127	0.3132	0.2428	0.5323	0.4543	0.3823	0.3029	0.4576	0.3666	0.3233	0.2468	0.4809	0.4100	0.3710	0.3018
			Wood	0.4307	0.3461	0.2560	0.1932	0.4633	0.3968	0.3307	0.2607	0.3770	0.3040	0.2475	0.1911	0.4055	0.3526	0.3019	0.2529
		Hurricane	Other	0.3452	0.2906	0.2318	0.1892	0.4013	0.3514	0.3177	0.2590	0.3033	0.2543	0.2241	0.1857	0.3542	0.3126	0.2910	0.2515
			Wood	0.2633	0.2236	0.1845	0.1539	0.3342	0.2962	0.2832	0.2307	0.2199	0.1890	0.1661	0.1466	0.2834	0.2578	0.2458	0.2191
	HVHZ	Hurricane	Other	0.3383	0.2848	0.2271	0.1854	0.3933	0.3443	0.3113	0.2538	0.2973	0.2492	0.2197	0.1820	0.3471	0.3064	0.2851	0.2464
			Wood	0.2581	0.2192	0.1808	0.1509	0.3275	0.2903	0.2776	0.2261	0.2155	0.1852	0.1628	0.1437	0.2778	0.2526	0.2409	0.2147

[1] Use Table 4-16 for FBC 2001 houses with reinforced concrete roof deck.

[2] FBC Roof Covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old).

[3] Non FBC Roof Covers (this part of the table is used with FBC Roof Covers to interpolate for 2001 FBC construction with roof covers 6 years old or more). See Section 4.2.5.

[4] Opening Protection is not required by the 2001 FBC for 100 mph design windspeeds. Hence, this row only applies to 2001 FBC homes that are further mitigated with opening protection.

[5] Opening protection is required within 1 mile of coast for 110 mph design windspeeds. For most locations in Florida in the 110 mph windzone, this row only applies to 2001 FBC homes mitigated with opening protection.

[6] This row included for: (a) Panhandle WBD exception; (b) interpolation of shutters less than "Hurricane" per Table 4-15; and (c) partially enclosed designs in the WBDR. Apply a factor of 0.98 to this row for partially enclosed designs, per Table 4-15.

[7] Use wood soffit row for the use of this table for any FBC 2006 construction.

[8] Secondary Factor 4 (all openings protected) have already been considered in the HVHZ.

Table 4-23. Terrain B Secondary Water Resistance Factors for 2001 FBC

Terrain B FBC 2001 Single Family SWR Factors[1]				Low Roof Slope (≤ 5:12)								Other Roof Slope (≥ 6:12)							
				Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile		Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Soffits	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC	100, 110	None	Other	0.945	0.959	0.980	0.980	0.965	0.978	0.980	0.980	0.962	0.980	0.980	0.980	0.976	0.980	0.980	0.980
			Wood	0.938	0.955	0.980	0.980	0.964	0.977	0.980	0.980	0.958	0.975	0.980	0.980	0.974	0.980	0.980	0.980
	≥ 120	Hurricane	Other	0.923	0.961	0.980	0.980	0.965	0.979	0.980	0.980	0.960	0.980	0.980	0.980	0.980	0.980	0.980	0.980
			Wood	0.924	0.966	0.980	0.980	0.968	0.979	0.980	0.980	0.962	0.980	0.980	0.980	0.980	0.980	0.980	0.980
Non-FBC	100, 110	None	Other	0.723	0.771	0.907	0.950	0.839	0.877	0.957	0.980	0.779	0.833	0.920	0.954	0.874	0.915	0.963	0.979
			Wood	0.722	0.772	0.917	0.957	0.843	0.876	0.960	0.983	0.775	0.830	0.926	0.959	0.873	0.913	0.967	0.981
	≥ 120	Hurricane	Other	0.705	0.780	0.914	0.957	0.836	0.888	0.960	0.980	0.773	0.840	0.928	0.965	0.879	0.919	0.968	0.985
			Wood	0.714	0.792	0.919	0.963	0.843	0.893	0.964	0.984	0.786	0.853	0.937	0.972	0.887	0.924	0.973	0.989

[1] These SWR factors must be determined by separate inspection or affadavit. SWR is not required by the FBC and is not typical of new construction.

[2] FBC roof covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

[3] Non-FBC roof covers (this part of the table is used with FBC to interpolate for 2001 FBC construction with roof covers 6 years old or more). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

Table 4-24. Terrain C Secondary Water Resistance Factors for 2001 FBC

Terrain C FBC 2001 Single Family SWR Factors[1]				Low Roof Slope (≤ 5:12)								Other Roof Slope (≥ 6:12)							
				Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile		Two Story Shingle		One Story Shingle		Two Story Tile		One Story Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Soffits	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100, 110	None	Other	0.948	0.950	0.977	0.980	0.958	0.968	0.980	0.980	0.966	0.973	0.980	0.980	0.974	0.980	0.980	0.980
			Wood	0.941	0.940	0.974	0.980	0.951	0.963	0.980	0.980	0.958	0.965	0.980	0.980	0.969	0.978	0.980	0.980
	≥ 120	Hurricane	Other	0.904	0.933	0.974	0.980	0.947	0.963	0.980	0.980	0.953	0.972	0.980	0.980	0.973	0.980	0.980	0.980
			Wood	0.899	0.936	0.975	0.980	0.946	0.963	0.980	0.980	0.950	0.972	0.980	0.980	0.973	0.980	0.980	0.980
Non-FBC[3]	no	None	Other	0.736	0.718	0.850	0.879	0.811	0.825	0.918	0.947	0.795	0.802	0.889	0.912	0.863	0.887	0.943	0.963
			Wood	0.737	0.703	0.875	0.889	0.806	0.818	0.928	0.950	0.786	0.779	0.904	0.914	0.852	0.878	0.947	0.964
	shutters	Hurricane	Other	0.649	0.698	0.845	0.884	0.786	0.830	0.919	0.950	0.743	0.798	0.881	0.918	0.854	0.895	0.942	0.966
			Wood	0.658	0.719	0.863	0.915	0.801	0.845	0.934	0.962	0.752	0.812	0.902	0.941	0.864	0.901	0.954	0.974

[1] These SWR factors must be determined by separate inspection or affadavit. SWR is not required by the FBC and is not typical of new construction.

[2] FBC roof covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

[3] Non-FBC roof covers (this part of the table is used with FBC to interpolate for 2001 FBC construction with roof covers 6 years old or more). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

5 Loss Relativities for Multi-Family Residences

5.1 General

This section presents the analysis of key wind mitigation features that influence physical damage and loss for multi-family (MF) residential buildings in a hurricane. The key construction features for MF residential buildings that influence hurricane losses were introduced in Section 1.4.2. As discussed in Section 2.5.2, MF residences are divided into three groups. The first group includes low-rise buildings (less than 60 feet high) with wood roof decks. These buildings typically have construction features very similar to single family (SF) homes. The second group includes low-rise buildings (less than 60 feet high) with roof decks other than wood (typically metal or concrete). The third group includes all buildings above 60 feet high. Table 2-7 summarizes the construction characteristics of Groups I, II, and III. Refer to decision tree in Section 2.5.2 for a simple approach to classify multi-family residences.

Table 5-1. Building Construction Groups for Multi-Family Residential Buildings

Group	*Height*	*Roof Deck Material*	*Typical Frame Construction*	*Model Building Height*
I	≤60 feet	Wood	Masonry or Wood Frame	2 stories
II	≤60 feet	Not wood	Steel or Reinforced Concrete	5 stories
III	>60 feet	Any	Steel or Reinforced Concrete	8 stories

This section is organized into three main sections: Group I buildings, Group II buildings, and Group III buildings. The analysis of each group is further divided into building code eras. Implementation of the loss relativities, in terms of insurance rate differentials and/or credits is presented in Section 6. Definitions of the wind-resistive features for MF residential buildings are given in Appendix A.

The main qualifications of the MF loss relativities are:

1. The relativities are based on the reductions in total insured loss due to the presence of hurricane windstorm mitigation features. Losses include covered wind damage to the building and contents as well as covered costs incurred due to loss of use of the building. For condominium buildings, it is assumed that any differentials in windstorm premiums will be shared by the condominium association, the condominium unit owners, and, potentially, condominium unit renters in direct proportion to their respective windstorm premiums. Similarly, for apartment buildings, it is assumed that any differentials in windstorm premiums will be shared by the building owner and the apartment renters in direct proportion to their respective windstorm premiums. A more rigorous allocation of rate differentials is possible, but such an analysis was not possible within the schedule and resources available for this project.
2. The relativities are based on 2% deductible. As discussed and illustrated in the 2002 report, the relativities are dependent on the deductible and the effect is nonlinear over the range from weak to strong buildings.
3. Rate differentials derived from the loss relativities are applicable only to the portion of the wind premium associated with the loss costs for the dwelling, its contents, and additional living expenses resulting from damage to the dwelling. The loss relativities should not be applied to any portion of the wind premium that is associated with the loss costs for attached or detached structures.[35]
4. The building is in reasonably good condition. In particular, the roof cover and windows/openings are not in a state of neglect and disrepair. Our suggestion is that buildings that are in a state of disrepair should not qualify for mitigation rate differentials until such components are brought

[35] As given in Table 2-14, we used 0% for appurtenant structures (generally referred to as Coverage B) in the modeled results. Equally important, we did not include any attached structures (such as pool and patio screen enclosures, which are often covered as part of Coverage A) in the modeling of the dwelling losses.

back into good condition. Also, the roof deck strength for wood roof decks must be at least deck strength A in order for the building to qualify for wind mitigation rate differentials.

5.2 Group I Buildings

The analysis of Group I MF residential buildings is divided into two major building code eras: pre-FBC and post-FBC. Pre-FBC construction refers to all site-built MF buildings built before the implementation of the 2001 Florida Building Code (permitted prior to March 1, 2002). Post-FBC construction refers to any Florida building permitted on or after March 1, 2002 and includes two eras (FBC 2001 and FBC 2006). This separation recognizes the changes brought about by the FBC and the fact that the methods used to verify the construction features may be different for existing and new construction.

5.2.1 Pre-FBC Construction

The development of loss relativities for Group I MF residential buildings built prior to the FBC follows the same approach used in Section 4.2 for pre-FBC single-family homes. For Group I buildings, the determination of the presence or absence of wind mitigation features for houses built prior to the FBC is made from an inspection/verification process. That is, since Group I buildings permitted before March 1, 2002 were built to different standards in different parts of the state, it was concluded that the determination of wind mitigation features should be accomplished though visual inspection on a building-by-building basis. In other words, it was not practical to evaluate and develop loss relativities for all the possible year-built construction eras on a statewide basis. Hence, the concept of verifiable wind mitigation features through an inspection process has driven the development of rate differentials for Group I buildings permitted prior to March 1, 2002.

The mitigation features for Group I construction follow from the single family residence features discussed in Section 4. New features include: roof cover type, roof slope, and soffits. We also include a flat roof shape for Group I. Group I construction is based on modeled 2 story buildings and we do not consider number of stories as a factor for Group I.

5.2.1.1 Loss Relativity Tables Normalized to Typical Construction

Table 5-2 through Table 5-5 are the loss relativity tables, normalized to typical construction. These tables are analogous to Table 4-5 through Table 4-8. The typical building corresponds to the low-slope other roof shape, non-tile and non-FBC roof cover, clips, Deck B, no shutters and wood soffits. This is the same typical building used to normalize the single family tables, except that for Group I, the building is two stories instead of one.

The range of relativities is less that the same range for the single family houses. For example, in Terrain B, the strongest building has a relativity that is 2.27 lower than the typical building, whereas the weakest building has a relativity that is 1.86 time larger than the typical building. The overall range is 4.2 vs. 7.5 for Terrain B single family.

In Terrain C, the strongest building has a relativity that is 3.75 times lower than the typical building and the weakest building has a relativity that is 1.58 times larger than the typical building. The overall range is 5.9, which is less than the overall Terrain C single family range of 10.3.

Table 5-2. Group I Terrain B Non-FBC, Normalized to Typical Building

Group I Terrain B-Normalized toTypical					Flat		Low Roof Slope (≤ 5:12)								Other Roof slope (≥ 6:12)							
					Built-Up		Non-tile				Tile				Non-tile				Tile			
							Other		Hip		Other		Hip		Other		Hip		Other		Hip	
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
Non-FBC	A	Toe Nails	None	Other			1.6106	1.3132	1.2365	1.0815	1.7966	1.5881	1.4680	1.3634	1.6198	1.3535	1.2347	1.0988	1.6786	1.4976	1.3578	1.2716
				Wood	1.8579	1.8330	1.3421	1.0943	1.0304	0.9012	1.4972	1.3234	1.2233	1.1362	1.3498	1.1279	1.0289	0.9157	1.3988	1.2480	1.1315	1.0597
			Hurricane	Other			1.2856	0.9533	0.9025	0.7162	1.5570	1.3278	1.2268	1.0995	1.1889	0.8752	0.8424	0.6822	1.4306	1.2348	1.1506	1.0464
				Wood	1.5021	1.3477	1.0713	0.7944	0.7521	0.5969	1.2975	1.1065	1.0224	0.9163	0.9908	0.7293	0.7020	0.5685	1.1922	1.0290	0.9588	0.8720
		Clips	None	Other			1.4724	1.1728	1.1053	0.9488	1.6697	1.4667	1.3579	1.2521	1.4011	1.1226	1.0267	0.8840	1.5105	1.3329	1.2201	1.1276
				Wood	1.7771	1.7128	1.2693	1.0110	0.9528	0.8179	1.4394	1.2644	1.1706	1.0794	1.2078	0.9678	0.8851	0.7621	1.3022	1.1491	1.0518	0.9721
			Hurricane	Other			1.2292	0.9001	0.8685	0.6790	1.5006	1.2762	1.1805	1.0553	1.1318	0.8194	0.8020	0.6432	1.3743	1.1816	1.1019	1.0044
				Wood	1.4896	1.3198	1.0597	0.7759	0.7487	0.5854	1.2936	1.1028	1.0206	0.9148	0.9757	0.7064	0.6914	0.5545	1.1847	1.0186	0.9499	0.8659
		Wraps	None	Other			1.3560	1.0633	1.0205	0.8650	1.5778	1.3836	1.2963	1.1966	1.2418	0.9614	0.9054	0.7580	1.4303	1.2504	1.1544	1.0655
				Wood	1.7363	1.6474	1.2107	0.9494	0.9111	0.7723	1.4087	1.2353	1.1574	1.0684	1.1087	0.8584	0.8084	0.6768	1.2771	1.1165	1.0307	0.9513
			Hurricane	Other			1.1800	0.8633	0.8337	0.6528	1.4482	1.2324	1.1412	1.0199	1.0833	0.7819	0.7688	0.6130	1.3243	1.1399	1.0626	0.9689
				Wood	1.4866	1.3161	1.0535	0.7708	0.7444	0.5829	1.2930	1.1004	1.0189	0.9106	0.9672	0.6981	0.6864	0.5473	1.1824	1.0177	0.9487	0.8651
	B	Toe Nails	None	Other			1.3304	1.0913	1.1453	1.0121	1.5578	1.3714	1.3725	1.2728	1.4659	1.2337	1.1883	1.0749	1.5193	1.3458	1.3140	1.2315
				Wood	1.2793	1.2697	1.1087	0.9094	0.9544	0.8434	1.2981	1.1429	1.1438	1.0607	1.2215	1.0281	0.9902	0.8958	1.2661	1.1215	1.0950	1.0262
			Hurricane	Other			0.9749	0.7121	0.8034	0.6509	1.2988	1.0930	1.1445	1.0317	0.9860	0.7120	0.7930	0.6469	1.2598	1.0679	1.1068	1.0064
				Wood	0.8672	0.7664	0.8124	0.5934	0.6695	0.5425	1.0823	0.9109	0.9538	0.8597	0.8217	0.5933	0.6609	0.5391	1.0498	0.8899	0.9224	0.8387
		Clips	None	Other			1.1600	0.9130	0.9802	0.8420	1.4108	1.2264	1.2349	1.1327	1.1990	0.9492	0.9590	0.8351	1.3402	1.1609	1.1401	1.0530
				Wood	1.1237	1.0701	1.0000	0.7870	0.8450	0.7259	1.2162	1.0573	1.0646	0.9765	1.0336	0.8183	0.8267	0.7199	1.1553	1.0008	0.9829	0.9077
			Hurricane	Other			0.9008	0.6299	0.7577	0.6015	1.2471	1.0448	1.1004	0.9909	0.9117	0.6337	0.7467	0.6032	1.2093	1.0224	1.0610	0.9685
				Wood	0.8262	0.6991	0.7765	0.5430	0.6532	0.5185	1.0750	0.9007	0.9486	0.8542	0.7860	0.5463	0.6437	0.5200	1.0425	0.8814	0.9147	0.8349
		Wraps	None	Other			1.0326	0.7831	0.8551	0.7168	1.3037	1.1132	1.1343	1.0298	1.0127	0.7548	0.7958	0.6628	1.2121	1.0313	1.0453	0.9554
				Wood	1.0314	0.9465	0.9220	0.6992	0.7635	0.6400	1.1640	0.9940	1.0128	0.9195	0.9042	0.6739	0.7105	0.5918	1.0823	0.9208	0.9333	0.8530
			Hurricane	Other			0.8616	0.5972	0.7236	0.5747	1.1979	1.0034	1.0561	0.9487	0.8695	0.5955	0.7095	0.5704	1.1632	0.9781	1.0213	0.9310
				Wood	0.8156	0.6841	0.7693	0.5332	0.6461	0.5131	1.0696	0.8959	0.9429	0.8471	0.7763	0.5317	0.6335	0.5093	1.0386	0.8733	0.9119	0.8312
	C	Toe Nails	None	Other			1.3256	1.0952	1.1409	1.0110	1.5433	1.3625	1.3810	1.2809	1.4532	1.2214	1.1943	1.0774	1.5118	1.3388	1.3083	1.2247
				Wood	1.2617	1.2213	1.1046	0.9127	0.9508	0.8425	1.2861	1.1354	1.1508	1.0674	1.2110	1.0178	0.9953	0.8978	1.2598	1.1157	1.0903	1.0206
			Hurricane	Other			0.9573	0.7090	0.8022	0.6511	1.2861	1.0888	1.1483	1.0300	0.9858	0.7120	0.7921	0.6471	1.2588	1.0657	1.1090	1.0131
				Wood	0.8292	0.7431	0.7978	0.5909	0.6685	0.5426	1.0717	0.9073	0.9569	0.8583	0.8215	0.5934	0.6601	0.5393	1.0490	0.8881	0.9242	0.8442
		Clips	None	Other			1.1470	0.9089	0.9745	0.8416	1.4036	1.2236	1.2316	1.1307	1.1981	0.9506	0.9531	0.8283	1.3308	1.1538	1.1451	1.0592
				Wood	1.0937	1.0487	0.9888	0.7835	0.8401	0.7256	1.2100	1.0548	1.0618	0.9748	1.0329	0.8195	0.8216	0.7140	1.1473	0.9947	0.9871	0.9131
			Hurricane	Other			0.8818	0.6280	0.7543	0.6015	1.2304	1.0375	1.0997	0.9878	0.9054	0.6300	0.7450	0.6029	1.2070	1.0175	1.0585	0.9680
				Wood	0.7833	0.6750	0.7601	0.5414	0.6503	0.5185	1.0607	0.8944	0.9480	0.8515	0.7805	0.5431	0.6423	0.5197	1.0405	0.8772	0.9125	0.8345
		Wraps	None	Other			1.0210	0.7844	0.8510	0.7114	1.2894	1.1067	1.1327	1.0294	1.0061	0.7539	0.7953	0.6620	1.2064	1.0265	1.0475	0.9576
				Wood	0.9824	0.9132	0.9116	0.7003	0.7598	0.6352	1.1513	0.9881	1.0113	0.9191	0.8983	0.6731	0.7101	0.5911	1.0772	0.9165	0.9353	0.8550
			Hurricane	Other			0.8472	0.5958	0.7192	0.5743	1.1802	0.9940	1.0533	0.9479	0.8597	0.5933	0.7065	0.5667	1.1568	0.9748	1.0182	0.9275
				Wood	0.7713	0.6562	0.7565	0.5319	0.6421	0.5127	1.0538	0.8875	0.9405	0.8464	0.7676	0.5297	0.6308	0.5060	1.0328	0.8704	0.9091	0.8282

Table 5-3. Group I Terrain B FBC, Normalized to Typical Building

Group I Terrain B-Normalized toTypical					Flat		Low Roof Slope (≤ 5:12)								Other Roof slope (≥ 6:12)							
					Built-Up		Non-tile				Tile				Non-tile				Tile			
							Other		Hip		Other		Hip		Other		Hip		Other		Hip	
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
FBC	A	Toe Nails	None	Other			1.2448	1.2053	1.0155	0.9951	1.2234	1.1934	1.0307	1.0167	1.2625	1.2500	1.0220	1.0192	1.1267	1.1153	0.9414	0.9364
				Wood	1.3927	1.3231	1.0373	1.0044	0.8463	0.8293	1.0195	0.9945	0.8589	0.8472	1.0521	1.0416	0.8517	0.8493	0.9389	0.9294	0.7845	0.7803
			Hurricane	Other			0.8756	0.8426	0.6314	0.6191	0.9494	0.9236	0.7539	0.7414	0.7881	0.7709	0.6005	0.5927	0.8621	0.8474	0.7154	0.7081
				Wood	0.9675	0.9503	0.7297	0.7021	0.5262	0.5159	0.7911	0.7697	0.6282	0.6178	0.6567	0.6424	0.5004	0.4939	0.7184	0.7062	0.5962	0.5901
		Clips	None	Other			1.1064	1.0715	0.8678	0.8531	1.1052	1.0812	0.9250	0.9129	1.0329	1.0182	0.8028	0.7954	0.9815	0.9677	0.7987	0.7939
				Wood	1.2798	1.2211	0.9538	0.9237	0.7481	0.7355	0.9527	0.9321	0.7974	0.7870	0.8904	0.8778	0.6921	0.6857	0.8461	0.8342	0.6885	0.6844
			Hurricane	Other			0.8234	0.7902	0.6000	0.5876	0.9161	0.8878	0.7209	0.7112	0.7346	0.7145	0.5683	0.5581	0.8220	0.8095	0.6811	0.6744
				Wood	0.9545	0.9419	0.7099	0.6812	0.5173	0.5066	0.7897	0.7654	0.6214	0.6131	0.6333	0.6159	0.4900	0.4812	0.7086	0.6979	0.5872	0.5814
		Wraps	None	Other			0.9878	0.9564	0.7861	0.7734	1.0294	1.0064	0.8724	0.8630	0.8741	0.8586	0.6696	0.6629	0.8919	0.8808	0.7422	0.7372
				Wood	1.2246	1.1633	0.8820	0.8539	0.7019	0.6905	0.9191	0.8986	0.7789	0.7705	0.7805	0.7666	0.5978	0.5918	0.7964	0.7865	0.6626	0.6583
			Hurricane	Other			0.7902	0.7567	0.5776	0.5631	0.8805	0.8544	0.6955	0.6862	0.7067	0.6856	0.5384	0.5288	0.7921	0.7802	0.6544	0.6500
				Wood	0.9506	0.9083	0.7056	0.6757	0.5157	0.5027	0.7862	0.7628	0.6210	0.6127	0.6310	0.6121	0.4807	0.4721	0.7072	0.6966	0.5843	0.5804
	B	Toe Nails	None	Other			1.0461	1.0103	0.9523	0.9335	1.0408	1.0143	0.9602	0.9467	1.1521	1.1392	0.9983	0.9941	1.0238	1.0101	0.9096	0.9048
				Wood	1.1667	1.1084	0.8718	0.8419	0.7936	0.7779	0.8673	0.8453	0.8002	0.7890	0.9601	0.9494	0.8319	0.8284	0.8532	0.8418	0.7580	0.7540
			Hurricane	Other			0.6538	0.6246	0.5758	0.5644	0.7628	0.7393	0.7008	0.6951	0.6476	0.6258	0.5714	0.5612	0.7446	0.7267	0.6896	0.6807
				Wood	0.7159	0.6801	0.5448	0.5205	0.4799	0.4703	0.6357	0.6161	0.5840	0.5792	0.5397	0.5215	0.4762	0.4676	0.6205	0.6056	0.5746	0.5673
		Clips	None	Other			0.8667	0.8326	0.7718	0.7575	0.9089	0.8853	0.8245	0.8142	0.8880	0.8675	0.7565	0.7496	0.8486	0.8318	0.7449	0.7392
				Wood	0.9924	0.9480	0.7472	0.7177	0.6653	0.6530	0.7835	0.7632	0.7108	0.7019	0.7655	0.7479	0.6522	0.6462	0.7316	0.7171	0.6421	0.6372
			Hurricane	Other			0.5790	0.5443	0.5330	0.5212	0.7265	0.7019	0.6708	0.6614	0.5794	0.5521	0.5314	0.5230	0.7061	0.6860	0.6524	0.6453
				Wood	0.6621	0.6290	0.4991	0.4692	0.4595	0.4493	0.6263	0.6051	0.5782	0.5701	0.4995	0.4759	0.4581	0.4509	0.6087	0.5913	0.5624	0.5563
		Wraps	None	Other			0.7377	0.7064	0.6431	0.6320	0.8073	0.7867	0.7220	0.7159	0.7083	0.6823	0.5887	0.5814	0.7278	0.7104	0.6563	0.6513
				Wood	0.8784	0.8345	0.6587	0.6307	0.5742	0.5643	0.7208	0.7024	0.6446	0.6392	0.6324	0.6092	0.5256	0.5191	0.6499	0.6343	0.5860	0.5815
			Hurricane	Other			0.5489	0.5138	0.5059	0.4924	0.6927	0.6724	0.6454	0.6347	0.5448	0.5177	0.4994	0.4917	0.6708	0.6563	0.6251	0.6171
				Wood	0.6489	0.6165	0.4901	0.4618	0.4517	0.4443	0.6185	0.6004	0.5762	0.5667	0.4864	0.4622	0.4500	0.4432	0.5989	0.5860	0.5604	0.5550
	C	Toe Nails	None	Other			1.0416	1.0095	0.9494	0.9290	1.0410	1.0189	0.9593	0.9462	1.1555	1.1427	1.0057	0.9996	1.0237	1.0094	0.9104	0.9057
				Wood	1.1639	1.1057	0.8680	0.8412	0.7912	0.7742	0.8675	0.8491	0.7994	0.7885	0.9629	0.9522	0.8381	0.8330	0.8530	0.8412	0.7586	0.7548
			Hurricane	Other			0.6443	0.6169	0.5753	0.5646	0.7523	0.7307	0.7020	0.6928	0.6453	0.6276	0.5664	0.5578	0.7404	0.7226	0.6851	0.6815
				Wood	0.7120	0.6764	0.5369	0.5141	0.4794	0.4705	0.6269	0.6089	0.5850	0.5773	0.5378	0.5230	0.4720	0.4649	0.6170	0.6021	0.5709	0.5679
		Clips	None	Other			0.8553	0.8223	0.7694	0.7561	0.9075	0.8842	0.8185	0.8111	0.8914	0.8710	0.7598	0.7539	0.8470	0.8309	0.7402	0.7357
				Wood	0.9875	0.9381	0.7373	0.7088	0.6633	0.6518	0.7823	0.7622	0.7056	0.6992	0.7684	0.7509	0.6550	0.6499	0.7301	0.7163	0.6381	0.6342
			Hurricane	Other			0.5697	0.5414	0.5304	0.5188	0.7177	0.6930	0.6703	0.6609	0.5748	0.5484	0.5304	0.5167	0.7011	0.6826	0.6527	0.6469
				Wood	0.6539	0.6212	0.4911	0.4667	0.4572	0.4473	0.6187	0.5974	0.5778	0.5697	0.4955	0.4727	0.4572	0.4455	0.6044	0.5885	0.5627	0.5577
		Wraps	None	Other			0.7286	0.6987	0.6431	0.6330	0.7990	0.7796	0.7209	0.7142	0.6958	0.6736	0.5880	0.5797	0.7277	0.7117	0.6557	0.6503
				Wood	0.8742	0.8358	0.6505	0.6238	0.5742	0.5652	0.7134	0.6961	0.6437	0.6377	0.6213	0.6014	0.5250	0.5176	0.6497	0.6355	0.5855	0.5806
			Hurricane	Other			0.5412	0.5110	0.5055	0.4942	0.6869	0.6632	0.6427	0.6344	0.5400	0.5126	0.5019	0.4932	0.6707	0.6542	0.6253	0.6189
				Wood	0.6422	0.6101	0.4832	0.4563	0.4513	0.4412	0.6133	0.5922	0.5738	0.5665	0.4821	0.4577	0.4481	0.4404	0.5989	0.5841	0.5583	0.5526

Table 5-4. Group I Terrain C Non-FBC, Normalized to Typical Building

Group I Terrain C-Normailized to Typical					Flat		Low Roof Slope (≤ 5:12)								Other Roof slope (≥ 6:12)							
					Built-Up		Non-tile				Tile				Non-tile				Tile			
							Other		Hip		Other		Hip		Other		Hip		Other		Hip	
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
Non-FBC	A	Toe Nails	None	Other			1.3430	1.1894	1.1531	1.0636	1.4068	1.2912	1.2480	1.1801	1.4533	1.3060	1.2162	1.1342	1.3512	1.2403	1.1421	1.0801
				Wood	1.5841	1.3347	1.2406	1.0997	1.0664	0.9843	1.2991	1.1931	1.1534	1.0912	1.3418	1.2067	1.1243	1.0490	1.2482	1.1464	1.0563	0.9995
			Hurricane	Other			0.8071	0.5877	0.5694	0.4181	0.9031	0.7431	0.7022	0.5966	0.7639	0.5431	0.5300	0.3924	0.8393	0.6947	0.6554	0.5677
				Wood	0.9632	0.6187	0.7490	0.5477	0.5309	0.3921	0.8370	0.6902	0.6527	0.5559	0.7093	0.5068	0.4947	0.3685	0.7785	0.6459	0.6098	0.5293
		Clips	None	Other			1.2732	1.1106	1.0901	0.9940	1.3408	1.2252	1.1670	1.1015	1.2878	1.1185	1.0354	0.9312	1.2015	1.0854	0.9564	0.8833
				Wood	1.5359	1.2616	1.1865	1.0359	1.0170	0.9280	1.2491	1.1421	1.0882	1.0275	1.2000	1.0433	0.9663	0.8699	1.1201	1.0126	0.8932	0.8255
			Hurricane	Other			0.7861	0.5597	0.5617	0.4050	0.8941	0.7343	0.6951	0.5887	0.7505	0.5217	0.5200	0.3813	0.8301	0.6852	0.6455	0.5585
				Wood	0.9542	0.6076	0.7355	0.5258	0.5277	0.3827	0.8355	0.6882	0.6516	0.5533	0.7026	0.4907	0.4891	0.3606	0.7762	0.6420	0.6061	0.5247
		Wraps	None	Other			1.2230	1.0600	1.0186	0.9220	1.2599	1.1435	1.1137	1.0499	1.1477	0.9627	0.8485	0.7307	1.0774	0.9555	0.8704	0.7945
				Wood	1.5012	1.2198	1.1498	0.9974	0.9587	0.8684	1.1842	1.0755	1.0476	0.9879	1.0794	0.9065	0.7997	0.6896	1.0136	0.8998	0.8202	0.7492
			Hurricane	Other			0.7786	0.5521	0.5537	0.3982	0.8865	0.7289	0.6897	0.5846	0.7350	0.5107	0.5124	0.3734	0.8213	0.6786	0.6412	0.5531
				Wood	0.9501	0.6031	0.7344	0.5227	0.5242	0.3789	0.8352	0.6880	0.6514	0.5531	0.6937	0.4840	0.4857	0.3557	0.7743	0.6409	0.6060	0.5237
	B	Toe Nails	None	Other			1.1743	1.0483	1.0733	0.9946	1.2466	1.1359	1.1572	1.0908	1.3463	1.2218	1.1699	1.0997	1.2272	1.1189	1.0923	1.0361
				Wood	1.2601	1.1781	1.0858	0.9703	0.9932	0.9210	1.1522	1.0506	1.0701	1.0092	1.2436	1.1294	1.0818	1.0174	1.1344	1.0350	1.0106	0.9590
			Hurricane	Other			0.5795	0.4082	0.4740	0.3579	0.7042	0.5558	0.6266	0.5357	0.5983	0.4059	0.4731	0.3559	0.6931	0.5464	0.6076	0.5266
				Wood	0.5328	0.4079	0.5401	0.3830	0.4433	0.3368	0.6546	0.5184	0.5833	0.4999	0.5574	0.3809	0.4426	0.3351	0.6444	0.5098	0.5660	0.4916
		Clips	None	Other			1.0718	0.9294	0.9754	0.8868	1.1592	1.0433	1.0384	0.9703	1.1417	0.9917	0.9691	0.8809	1.0306	0.9091	0.8615	0.7938
				Wood	1.1420	1.0448	1.0000	0.8682	0.9108	0.8287	1.0809	0.9736	0.9692	0.9060	1.0648	0.9259	0.9049	0.8233	0.9619	0.8494	0.8053	0.7426
			Hurricane	Other			0.5358	0.3483	0.4529	0.3311	0.6889	0.5418	0.6144	0.5232	0.5556	0.3511	0.4552	0.3322	0.6786	0.5315	0.5986	0.5144
				Wood	0.4940	0.3535	0.5037	0.3301	0.4270	0.3142	0.6455	0.5093	0.5765	0.4921	0.5221	0.3327	0.4291	0.3152	0.6360	0.4998	0.5618	0.4840
		Wraps	None	Other			1.0021	0.8537	0.8509	0.7568	1.0293	0.9071	0.8845	0.8071	0.9436	0.7747	0.7136	0.6066	0.8380	0.7020	0.6834	0.6022
				Wood	1.0605	0.9518	0.9432	0.8046	0.8019	0.7140	0.9687	0.8545	0.8334	0.7610	0.8886	0.7307	0.6737	0.5736	0.7899	0.6628	0.6454	0.5696
			Hurricane	Other			0.5252	0.3361	0.4469	0.3230	0.6810	0.5348	0.6093	0.5169	0.5426	0.3352	0.4449	0.3217	0.6683	0.5196	0.5870	0.5045
				Wood	0.4902	0.3446	0.4975	0.3208	0.4244	0.3086	0.6432	0.5065	0.5762	0.4898	0.5139	0.3200	0.4225	0.3074	0.6313	0.4923	0.5554	0.4782
	C	Toe Nails	None	Other			1.1683	1.0465	1.0719	0.9925	1.2415	1.1318	1.1564	1.0910	1.3472	1.2254	1.1785	1.1091	1.2254	1.1203	1.0970	1.0422
				Wood	1.2449	1.1755	1.0803	0.9686	0.9919	0.9191	1.1475	1.0468	1.0694	1.0094	1.2445	1.1327	1.0897	1.0260	1.1327	1.0363	1.0150	0.9647
			Hurricane	Other			0.5663	0.4048	0.4757	0.3588	0.6886	0.5513	0.6257	0.5359	0.5965	0.4063	0.4735	0.3553	0.6846	0.5430	0.6081	0.5275
				Wood	0.5024	0.4040	0.5280	0.3799	0.4449	0.3377	0.6403	0.5143	0.5825	0.5002	0.5557	0.3812	0.4429	0.3345	0.6366	0.5067	0.5664	0.4924
		Clips	None	Other			1.0632	0.9250	0.9686	0.8793	1.1525	1.0409	1.0366	0.9692	1.1313	0.9847	0.9759	0.8882	1.0253	0.9065	0.8661	0.7970
				Wood	1.1191	1.0417	0.9921	0.8641	0.9045	0.8218	1.0748	0.9714	0.9674	0.9050	1.0552	0.9194	0.9113	0.8300	0.9569	0.8470	0.8096	0.7455
			Hurricane	Other			0.5151	0.3420	0.4514	0.3303	0.6764	0.5355	0.6144	0.5234	0.5525	0.3480	0.4539	0.3328	0.6720	0.5265	0.5950	0.5141
				Wood	0.4563	0.3469	0.4846	0.3243	0.4256	0.3134	0.6339	0.5035	0.5765	0.4922	0.5192	0.3299	0.4279	0.3157	0.6298	0.4951	0.5586	0.4837
		Wraps	None	Other			0.9900	0.8440	0.8505	0.7570	1.0220	0.9026	0.8800	0.8018	0.9459	0.7787	0.7137	0.6081	0.8341	0.6997	0.6814	0.6036
				Wood	1.0317	0.9465	0.9320	0.7955	0.8016	0.7142	0.9619	0.8503	0.8292	0.7561	0.8908	0.7345	0.6737	0.5750	0.7863	0.6607	0.6436	0.5709
			Hurricane	Other			0.5022	0.3289	0.4436	0.3216	0.6674	0.5269	0.6067	0.5161	0.5362	0.3316	0.4416	0.3200	0.6613	0.5165	0.5864	0.5043
				Wood	0.4477	0.3360	0.4761	0.3141	0.4213	0.3073	0.6304	0.4992	0.5738	0.4890	0.5079	0.3166	0.4194	0.3058	0.6247	0.4894	0.5547	0.4780

Table 5-5. Group I Terrain C FBC, Normalized to Typical Building

Group I Terrain C-Normailized to Typical					Flat		Low Roof Slope (≤ 5:12)								Other Roof slope (≥ 6:12)							
					Built-Up		Non-tile				Tile				Non-tile				Tile			
							Other		Hip		Other		Hip		Other		Hip		Other		Hip	
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
FBC	A	Toe Nails	None	Other			1.1748	1.1405	1.0409	1.0173	1.1471	1.1199	1.0519	1.0314	1.2716	1.2628	1.0973	1.0936	1.0754	1.0675	0.9305	0.9270
				Wood	1.3471	1.3131	1.0863	1.0548	0.9635	0.9418	1.0609	1.0360	0.9735	0.9547	1.1751	1.1670	1.0152	1.0118	0.9951	0.9878	0.8622	0.8590
			Hurricane	Other			0.5611	0.5305	0.3819	0.3689	0.5819	0.5567	0.4421	0.4301	0.5076	0.4894	0.3558	0.3456	0.5263	0.5121	0.4114	0.4050
				Wood	0.6110	0.5929	0.5233	0.4952	0.3589	0.3470	0.5423	0.5192	0.4141	0.4031	0.4742	0.4575	0.3349	0.3256	0.4913	0.4783	0.3859	0.3801
		Clips	None	Other			1.0961	1.0637	0.9728	0.9498	1.0795	1.0543	0.9603	0.9447	1.0715	1.0602	0.8938	0.8886	0.9037	0.8939	0.7246	0.7197
				Wood	1.2674	1.2347	1.0225	0.9926	0.9084	0.8871	1.0072	0.9838	0.8968	0.8824	0.9998	0.9893	0.8352	0.8304	0.8444	0.8353	0.6786	0.6740
			Hurricane	Other			0.5361	0.5033	0.3695	0.3542	0.5730	0.5475	0.4346	0.4226	0.4843	0.4649	0.3442	0.3342	0.5180	0.5037	0.4044	0.3978
				Wood	0.5993	0.5821	0.5041	0.4736	0.3497	0.3356	0.5382	0.5146	0.4100	0.3997	0.4561	0.4381	0.3264	0.3171	0.4873	0.4740	0.3820	0.3759
		Wraps	None	Other			1.0434	1.0128	0.8988	0.8799	0.9944	0.9725	0.8988	0.8876	0.9185	0.9060	0.6828	0.6769	0.7695	0.7601	0.6224	0.6179
				Wood	1.2348	1.2031	0.9819	0.9533	0.8467	0.8290	0.9361	0.9156	0.8467	0.8363	0.8652	0.8535	0.6449	0.6394	0.7259	0.7171	0.5884	0.5842
			Hurricane	Other			0.5286	0.4956	0.3652	0.3492	0.5663	0.5423	0.4313	0.4202	0.4756	0.4556	0.3374	0.3265	0.5092	0.4959	0.3996	0.3936
				Wood	0.5969	0.5805	0.5008	0.4699	0.3481	0.3331	0.5360	0.5135	0.4098	0.3995	0.4512	0.4325	0.3220	0.3119	0.4827	0.4702	0.3802	0.3746
	B	Toe Nails	None	Other			1.0366	1.0069	0.9721	0.9494	1.0187	0.9938	0.9636	0.9458	1.1926	1.1832	1.0761	1.0736	0.9848	0.9748	0.9031	0.8997
				Wood	1.2007	1.1723	0.9595	0.9323	0.9004	0.8795	0.9431	0.9203	0.8925	0.8762	1.1027	1.0940	0.9957	0.9935	0.9120	0.9028	0.8371	0.8339
			Hurricane	Other			0.3930	0.3654	0.3269	0.3157	0.4268	0.4050	0.3924	0.3822	0.3858	0.3662	0.3202	0.3124	0.4138	0.3974	0.3818	0.3753
				Wood	0.4150	0.4015	0.3690	0.3437	0.3084	0.2982	0.4000	0.3800	0.3685	0.3591	0.3625	0.3445	0.3023	0.2951	0.3882	0.3731	0.3588	0.3528
		Clips	None	Other			0.9255	0.8932	0.8589	0.8404	0.9215	0.8995	0.8412	0.8282	0.9649	0.9491	0.8467	0.8424	0.7887	0.7763	0.6512	0.6460
				Wood	1.0644	1.0416	0.8645	0.8347	0.8029	0.7858	0.8609	0.8405	0.7866	0.7745	0.9011	0.8864	0.7916	0.7876	0.7379	0.7264	0.6106	0.6057
			Hurricane	Other			0.3407	0.3064	0.3025	0.2896	0.4155	0.3925	0.3829	0.3732	0.3367	0.3085	0.3008	0.2909	0.4003	0.3821	0.3699	0.3624
				Wood	0.3616	0.3462	0.3231	0.2914	0.2877	0.2758	0.3924	0.3711	0.3622	0.3532	0.3194	0.2932	0.2861	0.2770	0.3783	0.3615	0.3502	0.3432
		Wraps	None	Other			0.8454	0.8148	0.7362	0.7222	0.7825	0.7634	0.6674	0.6586	0.7620	0.7405	0.5757	0.5676	0.5718	0.5551	0.4602	0.4532
				Wood	0.9739	0.9291	0.7968	0.7683	0.6948	0.6817	0.7380	0.7202	0.6305	0.6223	0.7188	0.6988	0.5448	0.5372	0.5411	0.5255	0.4368	0.4303
			Hurricane	Other			0.3311	0.2950	0.2945	0.2809	0.4097	0.3862	0.3776	0.3681	0.3251	0.2945	0.2904	0.2791	0.3918	0.3728	0.3632	0.3548
				Wood	0.3536	0.3371	0.3162	0.2824	0.2820	0.2693	0.3896	0.3677	0.3596	0.3508	0.3106	0.2819	0.2782	0.2676	0.3729	0.3551	0.3462	0.3383
	C	Toe Nails	None	Other			1.0406	1.0099	0.9704	0.9488	1.0146	0.9901	0.9653	0.9481	1.1934	1.1844	1.0719	1.0692	0.9889	0.9792	0.9011	0.8979
				Wood	1.1962	1.1683	0.9632	0.9350	0.8988	0.8789	0.9393	0.9168	0.8941	0.8784	1.1033	1.0951	0.9919	0.9894	0.9158	0.9069	0.8352	0.8322
			Hurricane	Other			0.3875	0.3646	0.3273	0.3166	0.4200	0.4011	0.3922	0.3825	0.3836	0.3653	0.3217	0.3139	0.4115	0.3963	0.3817	0.3750
				Wood	0.4105	0.4003	0.3640	0.3430	0.3088	0.2990	0.3938	0.3764	0.3683	0.3594	0.3605	0.3436	0.3036	0.2965	0.3860	0.3721	0.3587	0.3525
		Clips	None	Other			0.9189	0.8906	0.8614	0.8428	0.9246	0.9019	0.8357	0.8239	0.9588	0.9444	0.8485	0.8438	0.7797	0.7672	0.6505	0.6451
				Wood	1.0543	1.0324	0.8585	0.8322	0.8052	0.7880	0.8637	0.8427	0.7814	0.7705	0.8954	0.8821	0.7933	0.7890	0.7295	0.7180	0.6099	0.6049
			Hurricane	Other			0.3287	0.3001	0.3008	0.2884	0.4069	0.3861	0.3810	0.3708	0.3348	0.3093	0.3001	0.2902	0.3981	0.3814	0.3691	0.3623
				Wood	0.3520	0.3407	0.3120	0.2855	0.2861	0.2746	0.3844	0.3652	0.3604	0.3509	0.3177	0.2940	0.2855	0.2763	0.3763	0.3608	0.3494	0.3431
		Wraps	None	Other			0.8352	0.8074	0.7352	0.7212	0.7774	0.7578	0.6626	0.6537	0.7611	0.7420	0.5780	0.5701	0.5681	0.5534	0.4596	0.4529
				Wood	0.9709	0.9242	0.7873	0.7613	0.6938	0.6807	0.7333	0.7149	0.6260	0.6176	0.7181	0.7002	0.5469	0.5395	0.5377	0.5239	0.4363	0.4300
			Hurricane	Other			0.3191	0.2899	0.2929	0.2799	0.3996	0.3797	0.3747	0.3643	0.3199	0.2920	0.2892	0.2779	0.3884	0.3712	0.3624	0.3556
				Wood	0.3420	0.3298	0.3050	0.2777	0.2805	0.2683	0.3802	0.3616	0.3570	0.3472	0.3057	0.2797	0.2770	0.2665	0.3698	0.3536	0.3454	0.3391

The differences in typical and strong and weak buildings indicate that the modeled reductions in loss are reasonable when compared to a typical building. These ranges are reduced over those obtained in Section 4 for single family houses due to the fact that the number of stories is not a factor for Group I buildings and the buildings are larger than single family houses. Larger buildings have a smaller percentage of the envelope that is near a corner or eave, where the negative pressure coefficients are the most severe. The introduction of the flat roof shape tends to increase the range, but does not make up the difference due to the consideration of only one model building height. Another consideration is that the loads have been updated and improved in the modeling of roof shape and these updates are reflected in the model results for sloped and flat roofs considered in Group I.

5.2.1.2 Loss Relativities Normalized to Weakest Construction

Table 5-6 through Table 5-9 provide the loss relativities for Group I construction normalized to the weakest building, which is the flat roof building for both Terrain B and C. The strongest building in both Terrain B and Terrain C corresponds to:

- Other Roof Slope ($\geq$ 6:12)
- Non-tile
- Hip
- SWR
- FBC Roof Cover
- Roof Deck C
- Wrap Roof-to Wall
- Hurricane Opening Protection
- Wood Soffits

The relativities of these buildings are 0.2370 in Terrain B and 0.1682 in Terrain C.

Similar to the analysis in Section 4 for single family residences, we see that tile roof coverings and roof slope can have both positive and negative impacts. In general, non-tile roof coverings produce lower relativities and high slope roofs are generally better than low-slope roofs.

5.2.1.3 Group I Secondary Factors

The secondary factors for Group I incorporate those in Table 4-15 for single family residences with the following exception:

- Reinforced concrete roof deck does not apply. Group I buildings must have wood roof decks. A group I building that has a reinforced concrete roof deck is treated as a Group II multifamily residence.

Two new secondary factors are considered for Group I buildings with a flat roof shape. These factors are parapets and rooftop equipment (RTE). Parapets of sufficient height can dramatically reduce the wind loads on a flat roof. Inadequately-restrained RTE is highly vulnerable to wind damage. If the restraints for the RTE fail, total replacement (vs. repair) of the RTE is generally required. These two features are rare for Group I buildings with wooden roof decks, but we have analyzed both parapets and RTE for Group I buildings.

Table 5-6. Group I Terrain B Non-FBC, Normalized to Weakest

Group I Terrain B-Normalized to Weakest					Flat		Low Roof Slope (≤ 5:12)								Other Roof slope (≥ 6:12)							
					Built-Up		Non-tile				Tile				Non-tile				Tile			
							Other		Hip		Other		Hip		Other		Hip		Other		Hip	
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
Non-FBC	A	Toe Nails	None	Other			0.8669	0.7068	0.6655	0.5821	0.9670	0.8548	0.7901	0.7338	0.8718	0.7285	0.6646	0.5914	0.9035	0.8060	0.7308	0.6844
				Wood	1.0000	0.9866	0.7224	0.5890	0.5546	0.4851	0.8058	0.7123	0.6584	0.6115	0.7265	0.6071	0.5538	0.4929	0.7529	0.6717	0.6090	0.5704
			Hurricane	Other			0.6920	0.5131	0.4858	0.3855	0.8380	0.7147	0.6603	0.5918	0.6399	0.4711	0.4534	0.3672	0.7700	0.6646	0.6193	0.5632
				Wood	0.8085	0.7254	0.5766	0.4276	0.4048	0.3213	0.6984	0.5956	0.5503	0.4932	0.5333	0.3926	0.3779	0.3060	0.6417	0.5539	0.5161	0.4693
		Clips	None	Other			0.7925	0.6312	0.5949	0.5107	0.8987	0.7894	0.7309	0.6739	0.7541	0.6042	0.5526	0.4758	0.8130	0.7174	0.6567	0.6069
				Wood	0.9565	0.9219	0.6832	0.5442	0.5128	0.4402	0.7747	0.6805	0.6301	0.5810	0.6501	0.5209	0.4764	0.4102	0.7009	0.6185	0.5661	0.5232
			Hurricane	Other			0.6616	0.4844	0.4674	0.3655	0.8077	0.6869	0.6354	0.5680	0.6092	0.4410	0.4317	0.3462	0.7397	0.6360	0.5931	0.5406
				Wood	0.8018	0.7103	0.5704	0.4176	0.4030	0.3151	0.6963	0.5936	0.5493	0.4924	0.5252	0.3802	0.3721	0.2985	0.6377	0.5482	0.5113	0.4660
		Wraps	None	Other			0.7298	0.5723	0.5492	0.4656	0.8492	0.7447	0.6977	0.6441	0.6684	0.5175	0.4873	0.4080	0.7698	0.6730	0.6213	0.5735
				Wood	0.9345	0.8867	0.6516	0.5110	0.4904	0.4157	0.7582	0.6649	0.6230	0.5751	0.5968	0.4620	0.4351	0.3643	0.6874	0.6009	0.5547	0.5120
			Hurricane	Other			0.6351	0.4647	0.4487	0.3514	0.7795	0.6633	0.6142	0.5490	0.5831	0.4208	0.4138	0.3299	0.7128	0.6135	0.5719	0.5215
				Wood	0.8001	0.7084	0.5671	0.4149	0.4007	0.3137	0.6960	0.5923	0.5484	0.4901	0.5206	0.3757	0.3694	0.2946	0.6364	0.5478	0.5106	0.4656
	B	Toe Nails	None	Other			0.7161	0.5874	0.6164	0.5447	0.8384	0.7382	0.7387	0.6851	0.7890	0.6640	0.6396	0.5786	0.8177	0.7244	0.7072	0.6628
				Wood	0.6886	0.6834	0.5967	0.4895	0.5137	0.4539	0.6987	0.6151	0.6156	0.5709	0.6575	0.5533	0.5330	0.4821	0.6814	0.6036	0.5894	0.5524
			Hurricane	Other			0.5247	0.3833	0.4324	0.3504	0.6991	0.5883	0.6160	0.5553	0.5307	0.3832	0.4268	0.3482	0.6781	0.5748	0.5957	0.5417
				Wood	0.4667	0.4125	0.4373	0.3194	0.3603	0.2920	0.5825	0.4903	0.5134	0.4627	0.4422	0.3193	0.3557	0.2901	0.5650	0.4790	0.4964	0.4514
		Clips	None	Other			0.6244	0.4914	0.5276	0.4532	0.7594	0.6601	0.6647	0.6097	0.6453	0.5109	0.5162	0.4495	0.7213	0.6249	0.6136	0.5667
				Wood	0.6048	0.5760	0.5382	0.4236	0.4548	0.3907	0.6546	0.5691	0.5730	0.5256	0.5563	0.4404	0.4450	0.3875	0.6218	0.5387	0.5290	0.4886
			Hurricane	Other			0.4848	0.3390	0.4078	0.3237	0.6712	0.5624	0.5923	0.5333	0.4907	0.3411	0.4019	0.3247	0.6509	0.5503	0.5711	0.5213
				Wood	0.4447	0.3763	0.4180	0.2923	0.3516	0.2791	0.5786	0.4848	0.5106	0.4598	0.4230	0.2940	0.3465	0.2799	0.5611	0.4744	0.4923	0.4494
		Wraps	None	Other			0.5558	0.4215	0.4602	0.3858	0.7017	0.5992	0.6105	0.5543	0.5451	0.4063	0.4283	0.3567	0.6524	0.5551	0.5626	0.5142
				Wood	0.5551	0.5094	0.4962	0.3763	0.4109	0.3445	0.6265	0.5350	0.5451	0.4949	0.4867	0.3627	0.3824	0.3185	0.5825	0.4956	0.5023	0.4591
			Hurricane	Other			0.4637	0.3214	0.3895	0.3093	0.6448	0.5401	0.5684	0.5106	0.4680	0.3205	0.3819	0.3070	0.6261	0.5264	0.5497	0.5011
				Wood	0.4390	0.3682	0.4141	0.2870	0.3477	0.2762	0.5757	0.4822	0.5075	0.4559	0.4178	0.2862	0.3410	0.2741	0.5590	0.4700	0.4908	0.4474
	C	Toe Nails	None	Other			0.7135	0.5895	0.6141	0.5441	0.8307	0.7334	0.7433	0.6894	0.7821	0.6574	0.6428	0.5799	0.8137	0.7206	0.7042	0.6592
				Wood	0.6791	0.6573	0.5946	0.4912	0.5117	0.4535	0.6922	0.6111	0.6194	0.5745	0.6518	0.5478	0.5357	0.4832	0.6781	0.6005	0.5868	0.5493
			Hurricane	Other			0.5153	0.3816	0.4318	0.3505	0.6922	0.5860	0.6181	0.5544	0.5306	0.3832	0.4263	0.3483	0.6776	0.5736	0.5969	0.5453
				Wood	0.4463	0.4000	0.4294	0.3180	0.3598	0.2921	0.5768	0.4884	0.5150	0.4620	0.4422	0.3194	0.3553	0.2903	0.5646	0.4780	0.4974	0.4544
		Clips	None	Other			0.6173	0.4892	0.5245	0.4530	0.7555	0.6586	0.6629	0.6086	0.6449	0.5116	0.5130	0.4458	0.7163	0.6210	0.6163	0.5701
				Wood	0.5887	0.5645	0.5322	0.4217	0.4521	0.3905	0.6513	0.5677	0.5715	0.5247	0.5559	0.4411	0.4422	0.3843	0.6175	0.5354	0.5313	0.4914
			Hurricane	Other			0.4746	0.3380	0.4060	0.3237	0.6623	0.5584	0.5919	0.5317	0.4873	0.3391	0.4010	0.3245	0.6497	0.5477	0.5697	0.5210
				Wood	0.4216	0.3633	0.4091	0.2914	0.3500	0.2791	0.5709	0.4814	0.5102	0.4583	0.4201	0.2923	0.3457	0.2797	0.5601	0.4721	0.4911	0.4491
		Wraps	None	Other			0.5495	0.4222	0.4580	0.3829	0.6940	0.5956	0.6096	0.5541	0.5415	0.4057	0.4281	0.3563	0.6493	0.5525	0.5638	0.5154
				Wood	0.5288	0.4915	0.4906	0.3769	0.4090	0.3419	0.6197	0.5318	0.5443	0.4947	0.4835	0.3623	0.3822	0.3181	0.5798	0.4933	0.5034	0.4602
			Hurricane	Other			0.4560	0.3207	0.3871	0.3091	0.6352	0.5350	0.5669	0.5102	0.4627	0.3193	0.3803	0.3050	0.6226	0.5247	0.5480	0.4992
				Wood	0.4151	0.3532	0.4072	0.2863	0.3456	0.2760	0.5672	0.4777	0.5062	0.4555	0.4131	0.2851	0.3395	0.2724	0.5559	0.4685	0.4893	0.4457

Table 5-7. Terrain B FBC, Normalized to Weakest

Group I Terrain B-Normalized to Weakest					Flat		Low Roof Slope (≤ 5:12)								Other Roof slope (≥ 6:12)							
					Built-Up		Non-tile				Tile				Non-tile				Tile			
							Other		Hip		Other		Hip		Other		Hip		Other		Hip	
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
FBC	A	Toe Nails	None	Other			0.6700	0.6487	0.5466	0.5356	0.6585	0.6423	0.5548	0.5472	0.6795	0.6728	0.5501	0.5486	0.6064	0.6003	0.5067	0.5040
				Wood	0.7496	0.7121	0.5583	0.5406	0.4555	0.4463	0.5488	0.5353	0.4623	0.4560	0.5663	0.5606	0.4584	0.4571	0.5054	0.5002	0.4223	0.4200
			Hurricane	Other			0.4713	0.4535	0.3399	0.3332	0.5110	0.4971	0.4058	0.3990	0.4242	0.4149	0.3232	0.3190	0.4640	0.4561	0.3851	0.3811
				Wood	0.5207	0.5115	0.3927	0.3779	0.2832	0.2777	0.4258	0.4143	0.3381	0.3325	0.3535	0.3458	0.2694	0.2658	0.3867	0.3801	0.3209	0.3176
		Clips	None	Other			0.5955	0.5767	0.4671	0.4592	0.5949	0.5820	0.4978	0.4914	0.5559	0.5480	0.4321	0.4281	0.5283	0.5209	0.4299	0.4273
				Wood	0.6888	0.6572	0.5134	0.4972	0.4027	0.3959	0.5128	0.5017	0.4292	0.4236	0.4793	0.4725	0.3725	0.3691	0.4554	0.4490	0.3706	0.3684
			Hurricane	Other			0.4432	0.4253	0.3229	0.3163	0.4931	0.4778	0.3880	0.3828	0.3954	0.3846	0.3059	0.3004	0.4424	0.4357	0.3666	0.3630
				Wood	0.5137	0.5069	0.3821	0.3667	0.2784	0.2727	0.4251	0.4119	0.3345	0.3300	0.3409	0.3315	0.2637	0.2590	0.3814	0.3756	0.3160	0.3129
		Wraps	None	Other			0.5317	0.5148	0.4231	0.4163	0.5541	0.5417	0.4696	0.4645	0.4705	0.4621	0.3604	0.3568	0.4801	0.4741	0.3995	0.3968
				Wood	0.6591	0.6261	0.4747	0.4596	0.3778	0.3717	0.4947	0.4837	0.4193	0.4147	0.4201	0.4126	0.3218	0.3185	0.4286	0.4233	0.3567	0.3543
			Hurricane	Other			0.4253	0.4073	0.3109	0.3031	0.4739	0.4598	0.3744	0.3693	0.3804	0.3690	0.2898	0.2846	0.4263	0.4199	0.3522	0.3499
				Wood	0.5117	0.4889	0.3798	0.3637	0.2776	0.2706	0.4231	0.4106	0.3342	0.3298	0.3396	0.3295	0.2587	0.2541	0.3807	0.3749	0.3145	0.3124
	B	Toe Nails	None	Other			0.5631	0.5438	0.5126	0.5024	0.5602	0.5459	0.5168	0.5096	0.6201	0.6132	0.5373	0.5351	0.5511	0.5437	0.4896	0.4870
				Wood	0.6280	0.5966	0.4692	0.4532	0.4272	0.4187	0.4668	0.4550	0.4307	0.4246	0.5168	0.5110	0.4478	0.4459	0.4592	0.4531	0.4080	0.4058
			Hurricane	Other			0.3519	0.3362	0.3099	0.3038	0.4106	0.3979	0.3772	0.3741	0.3486	0.3368	0.3075	0.3020	0.4008	0.3911	0.3712	0.3664
				Wood	0.3853	0.3661	0.2932	0.2801	0.2583	0.2531	0.3421	0.3316	0.3143	0.3118	0.2905	0.2807	0.2563	0.2517	0.3340	0.3259	0.3093	0.3053
		Clips	None	Other			0.4665	0.4481	0.4154	0.4077	0.4892	0.4765	0.4438	0.4382	0.4780	0.4669	0.4072	0.4034	0.4567	0.4477	0.4009	0.3979
				Wood	0.5342	0.5103	0.4022	0.3863	0.3581	0.3515	0.4217	0.4108	0.3825	0.3778	0.4120	0.4025	0.3510	0.3478	0.3937	0.3860	0.3456	0.3430
			Hurricane	Other			0.3116	0.2930	0.2869	0.2805	0.3910	0.3778	0.3610	0.3560	0.3118	0.2972	0.2860	0.2815	0.3800	0.3692	0.3511	0.3473
				Wood	0.3563	0.3385	0.2687	0.2526	0.2473	0.2418	0.3371	0.3257	0.3112	0.3069	0.2688	0.2562	0.2466	0.2427	0.3276	0.3183	0.3027	0.2994
		Wraps	None	Other			0.3971	0.3802	0.3462	0.3402	0.4345	0.4234	0.3886	0.3853	0.3812	0.3672	0.3169	0.3130	0.3918	0.3824	0.3533	0.3505
				Wood	0.4728	0.4491	0.3545	0.3395	0.3091	0.3037	0.3880	0.3781	0.3470	0.3440	0.3404	0.3279	0.2829	0.2794	0.3498	0.3414	0.3154	0.3130
			Hurricane	Other			0.2954	0.2766	0.2723	0.2650	0.3728	0.3619	0.3474	0.3416	0.2932	0.2786	0.2688	0.2646	0.3611	0.3532	0.3364	0.3322
				Wood	0.3493	0.3318	0.2638	0.2485	0.2431	0.2391	0.3329	0.3232	0.3101	0.3050	0.2618	0.2488	0.2422	0.2386	0.3224	0.3154	0.3016	0.2987
	C	Toe Nails	None	Other			0.5606	0.5433	0.5110	0.5000	0.5603	0.5484	0.5163	0.5093	0.6219	0.6150	0.5413	0.5380	0.5510	0.5433	0.4900	0.4875
				Wood	0.6265	0.5951	0.4672	0.4528	0.4258	0.4167	0.4669	0.4570	0.4303	0.4244	0.5183	0.5125	0.4511	0.4483	0.4591	0.4527	0.4083	0.4062
			Hurricane	Other			0.3468	0.3320	0.3096	0.3039	0.4049	0.3933	0.3778	0.3729	0.3473	0.3378	0.3049	0.3002	0.3985	0.3889	0.3687	0.3668
				Wood	0.3832	0.3641	0.2890	0.2767	0.2580	0.2532	0.3374	0.3278	0.3149	0.3107	0.2894	0.2815	0.2541	0.2502	0.3321	0.3241	0.3073	0.3057
		Clips	None	Other			0.4604	0.4426	0.4141	0.4070	0.4884	0.4759	0.4406	0.4366	0.4798	0.4688	0.4089	0.4058	0.4559	0.4472	0.3984	0.3960
				Wood	0.5315	0.5049	0.3969	0.3815	0.3570	0.3508	0.4211	0.4103	0.3798	0.3763	0.4136	0.4042	0.3525	0.3498	0.3930	0.3855	0.3435	0.3414
			Hurricane	Other			0.3066	0.2914	0.2855	0.2793	0.3863	0.3730	0.3608	0.3557	0.3094	0.2951	0.2855	0.2781	0.3773	0.3674	0.3513	0.3482
				Wood	0.3520	0.3344	0.2643	0.2512	0.2461	0.2407	0.3330	0.3215	0.3110	0.3066	0.2667	0.2544	0.2461	0.2398	0.3253	0.3167	0.3029	0.3002
		Wraps	None	Other			0.3922	0.3760	0.3461	0.3407	0.4301	0.4196	0.3880	0.3844	0.3745	0.3626	0.3165	0.3120	0.3917	0.3831	0.3529	0.3500
				Wood	0.4706	0.4498	0.3501	0.3358	0.3091	0.3042	0.3840	0.3747	0.3465	0.3432	0.3344	0.3237	0.2826	0.2786	0.3497	0.3420	0.3151	0.3125
			Hurricane	Other			0.2913	0.2750	0.2721	0.2660	0.3697	0.3570	0.3459	0.3415	0.2906	0.2759	0.2701	0.2655	0.3610	0.3521	0.3365	0.3331
				Wood	0.3457	0.3284	0.2601	0.2456	0.2429	0.2375	0.3301	0.3187	0.3089	0.3049	0.2595	0.2464	0.2412	0.2370	0.3223	0.3144	0.3005	0.2974

Table 5-8. Group I Terrain C Non-FBC, Normalized to Weakest

Group I Terrain C- Normalized to Weakest					Flat		Low Roof Slope (≤ 5:12)								Other Roof slope (≥ 6:12)							
					Built-Up		Non-tile				Tile				Non-tile				Tile			
							Other		Hip		Other		Hip		Other		Hip		Other		Hip	
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
Non-FBC	A	Toe Nails	None	Other			0.8478	0.7509	0.7279	0.6714	0.8881	0.8151	0.7878	0.7450	0.9175	0.8244	0.7678	0.7160	0.8530	0.7830	0.7210	0.6819
				Wood	1.0000	0.8426	0.7832	0.6942	0.6732	0.6214	0.8201	0.7532	0.7281	0.6888	0.8471	0.7617	0.7097	0.6622	0.7879	0.7237	0.6668	0.6309
			Hurricane	Other			0.5095	0.3710	0.3595	0.2640	0.5701	0.4691	0.4433	0.3766	0.4822	0.3429	0.3346	0.2477	0.5298	0.4386	0.4137	0.3584
				Wood	0.6080	0.3906	0.4728	0.3457	0.3351	0.2475	0.5284	0.4357	0.4120	0.3509	0.4478	0.3199	0.3123	0.2326	0.4914	0.4077	0.3849	0.3342
		Clips	None	Other			0.8037	0.7011	0.6882	0.6275	0.8464	0.7735	0.7367	0.6953	0.8129	0.7061	0.6536	0.5879	0.7585	0.6852	0.6038	0.5576
				Wood	0.9696	0.7964	0.7490	0.6540	0.6420	0.5858	0.7886	0.7210	0.6870	0.6486	0.7575	0.6586	0.6100	0.5491	0.7071	0.6392	0.5639	0.5211
			Hurricane	Other			0.4963	0.3533	0.3546	0.2557	0.5644	0.4635	0.4388	0.3716	0.4738	0.3293	0.3283	0.2407	0.5240	0.4325	0.4075	0.3526
				Wood	0.6024	0.3836	0.4643	0.3320	0.3331	0.2416	0.5274	0.4345	0.4113	0.3493	0.4435	0.3098	0.3088	0.2277	0.4900	0.4053	0.3826	0.3313
		Wraps	None	Other			0.7721	0.6692	0.6430	0.5820	0.7954	0.7219	0.7031	0.6628	0.7245	0.6077	0.5356	0.4613	0.6801	0.6032	0.5495	0.5015
				Wood	0.9477	0.7700	0.7258	0.6296	0.6052	0.5482	0.7476	0.6789	0.6613	0.6237	0.6814	0.5722	0.5048	0.4353	0.6399	0.5680	0.5178	0.4730
			Hurricane	Other			0.4915	0.3485	0.3495	0.2514	0.5596	0.4602	0.4354	0.3691	0.4640	0.3224	0.3235	0.2357	0.5185	0.4284	0.4048	0.3492
				Wood	0.5998	0.3807	0.4636	0.3300	0.3309	0.2392	0.5273	0.4343	0.4112	0.3492	0.4379	0.3056	0.3066	0.2246	0.4888	0.4046	0.3825	0.3306
	B	Toe Nails	None	Other			0.7413	0.6618	0.6776	0.6279	0.7869	0.7171	0.7305	0.6886	0.8499	0.7713	0.7386	0.6942	0.7747	0.7063	0.6895	0.6540
				Wood	0.7955	0.7437	0.6855	0.6125	0.6270	0.5814	0.7273	0.6632	0.6755	0.6371	0.7851	0.7130	0.6829	0.6423	0.7161	0.6534	0.6380	0.6054
			Hurricane	Other			0.3658	0.2577	0.2992	0.2259	0.4446	0.3509	0.3955	0.3381	0.3777	0.2562	0.2987	0.2247	0.4376	0.3449	0.3836	0.3324
				Wood	0.3363	0.2575	0.3410	0.2418	0.2799	0.2126	0.4132	0.3273	0.3682	0.3156	0.3519	0.2404	0.2794	0.2115	0.4068	0.3218	0.3573	0.3103
		Clips	None	Other			0.6766	0.5867	0.6158	0.5598	0.7318	0.6586	0.6556	0.6125	0.7207	0.6261	0.6117	0.5561	0.6506	0.5739	0.5439	0.5011
				Wood	0.7209	0.6596	0.6313	0.5481	0.5750	0.5232	0.6824	0.6146	0.6118	0.5720	0.6722	0.5845	0.5712	0.5197	0.6072	0.5362	0.5084	0.4688
			Hurricane	Other			0.3382	0.2199	0.2859	0.2090	0.4349	0.3420	0.3878	0.3303	0.3507	0.2216	0.2873	0.2097	0.4284	0.3356	0.3779	0.3247
				Wood	0.3118	0.2231	0.3180	0.2084	0.2695	0.1983	0.4075	0.3215	0.3639	0.3106	0.3296	0.2100	0.2709	0.1990	0.4015	0.3155	0.3547	0.3055
		Wraps	None	Other			0.6326	0.5389	0.5371	0.4778	0.6498	0.5727	0.5584	0.5095	0.5957	0.4890	0.4505	0.3829	0.5290	0.4432	0.4314	0.3802
				Wood	0.6695	0.6009	0.5955	0.5079	0.5062	0.4508	0.6115	0.5394	0.5261	0.4804	0.5610	0.4613	0.4253	0.3621	0.4986	0.4184	0.4074	0.3596
			Hurricane	Other			0.3315	0.2122	0.2821	0.2039	0.4299	0.3376	0.3846	0.3263	0.3425	0.2116	0.2808	0.2031	0.4219	0.3280	0.3706	0.3185
				Wood	0.3095	0.2175	0.3141	0.2025	0.2679	0.1948	0.4060	0.3198	0.3637	0.3092	0.3244	0.2020	0.2667	0.1941	0.3985	0.3108	0.3506	0.3019
	C	Toe Nails	None	Other			0.7375	0.6607	0.6767	0.6265	0.7837	0.7145	0.7300	0.6887	0.8505	0.7735	0.7440	0.7001	0.7736	0.7072	0.6925	0.6579
				Wood	0.7858	0.7421	0.6820	0.6115	0.6262	0.5802	0.7244	0.6608	0.6751	0.6372	0.7856	0.7150	0.6879	0.6477	0.7151	0.6542	0.6407	0.6090
			Hurricane	Other			0.3575	0.2556	0.3003	0.2265	0.4347	0.3481	0.3950	0.3383	0.3765	0.2565	0.2989	0.2243	0.4322	0.3428	0.3839	0.3330
				Wood	0.3171	0.2550	0.3333	0.2398	0.2808	0.2132	0.4042	0.3247	0.3677	0.3157	0.3508	0.2407	0.2796	0.2112	0.4019	0.3199	0.3576	0.3108
		Clips	None	Other			0.6712	0.5839	0.6115	0.5551	0.7276	0.6571	0.6544	0.6118	0.7142	0.6216	0.6161	0.5607	0.6472	0.5723	0.5468	0.5031
				Wood	0.7065	0.6576	0.6263	0.5455	0.5710	0.5188	0.6785	0.6132	0.6107	0.5713	0.6661	0.5804	0.5753	0.5240	0.6041	0.5347	0.5111	0.4706
			Hurricane	Other			0.3252	0.2159	0.2850	0.2085	0.4270	0.3381	0.3879	0.3304	0.3488	0.2197	0.2865	0.2101	0.4242	0.3324	0.3756	0.3246
				Wood	0.2880	0.2190	0.3059	0.2047	0.2687	0.1979	0.4002	0.3178	0.3640	0.3107	0.3277	0.2082	0.2701	0.1993	0.3976	0.3126	0.3526	0.3053
		Wraps	None	Other			0.6250	0.5328	0.5369	0.4779	0.6452	0.5698	0.5555	0.5062	0.5971	0.4916	0.4505	0.3839	0.5266	0.4417	0.4302	0.3810
				Wood	0.6513	0.5975	0.5883	0.5022	0.5060	0.4509	0.6072	0.5368	0.5234	0.4773	0.5623	0.4637	0.4253	0.3630	0.4964	0.4171	0.4063	0.3604
			Hurricane	Other			0.3170	0.2076	0.2800	0.2030	0.4213	0.3326	0.3830	0.3258	0.3385	0.2093	0.2788	0.2020	0.4174	0.3260	0.3702	0.3183
				Wood	0.2826	0.2121	0.3005	0.1983	0.2659	0.1940	0.3980	0.3151	0.3622	0.3087	0.3206	0.1999	0.2648	0.1930	0.3944	0.3090	0.3502	0.3018

Table 5-9. Group I Terrain C FBC, Normalized to Weakest

Group I Terrain C- Normalized to Weakest					Flat		Low Roof Slope (≤ 5:12)								Other Roof slope (≥ 6:12)							
					Built-Up		Non-tile				Tile				Non-tile				Tile			
							Other		Hip		Other		Hip		Other		Hip		Other		Hip	
Roof Cover	Roof Deck	Roof-Wall	Opening Prot.	Soffits	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR	No SWR	SWR
FBC	A	Toe Nails	None	Other			0.7416	0.7200	0.6571	0.6422	0.7241	0.7070	0.6640	0.6511	0.8027	0.7972	0.6927	0.6904	0.6789	0.6739	0.5874	0.5852
				Wood	0.8504	0.8290	0.6857	0.6659	0.6082	0.5945	0.6697	0.6540	0.6146	0.6027	0.7418	0.7367	0.6409	0.6388	0.6282	0.6236	0.5443	0.5422
			Hurricane	Other			0.3542	0.3349	0.2411	0.2329	0.3673	0.3514	0.2791	0.2715	0.3204	0.3090	0.2246	0.2182	0.3322	0.3233	0.2597	0.2557
				Wood	0.3857	0.3743	0.3303	0.3126	0.2265	0.2190	0.3423	0.3278	0.2614	0.2545	0.2993	0.2888	0.2114	0.2055	0.3101	0.3019	0.2436	0.2399
		Clips	None	Other			0.6919	0.6715	0.6141	0.5996	0.6815	0.6656	0.6062	0.5964	0.6764	0.6693	0.5642	0.5610	0.5705	0.5643	0.4575	0.4543
				Wood	0.8001	0.7795	0.6455	0.6266	0.5734	0.5600	0.6358	0.6211	0.5661	0.5570	0.6311	0.6245	0.5272	0.5242	0.5330	0.5273	0.4284	0.4255
			Hurricane	Other			0.3385	0.3177	0.2332	0.2236	0.3617	0.3456	0.2743	0.2668	0.3058	0.2935	0.2173	0.2110	0.3270	0.3180	0.2553	0.2511
				Wood	0.3783	0.3674	0.3182	0.2990	0.2208	0.2118	0.3397	0.3248	0.2588	0.2523	0.2879	0.2765	0.2060	0.2002	0.3076	0.2992	0.2412	0.2373
		Wraps	None	Other			0.6587	0.6394	0.5674	0.5554	0.6277	0.6139	0.5674	0.5603	0.5798	0.5720	0.4311	0.4273	0.4857	0.4798	0.3929	0.3900
				Wood	0.7795	0.7595	0.6199	0.6018	0.5345	0.5234	0.5909	0.5780	0.5345	0.5279	0.5462	0.5388	0.4071	0.4036	0.4582	0.4527	0.3714	0.3688
			Hurricane	Other			0.3337	0.3129	0.2306	0.2205	0.3575	0.3423	0.2723	0.2653	0.3002	0.2876	0.2130	0.2061	0.3215	0.3130	0.2523	0.2485
				Wood	0.3768	0.3665	0.3161	0.2967	0.2197	0.2103	0.3384	0.3242	0.2587	0.2522	0.2848	0.2731	0.2033	0.1969	0.3047	0.2968	0.2400	0.2365
	B	Toe Nails	None	Other			0.6544	0.6357	0.6137	0.5993	0.6431	0.6274	0.6083	0.5970	0.7529	0.7469	0.6793	0.6778	0.6217	0.6153	0.5701	0.5679
				Wood	0.7580	0.7400	0.6057	0.5885	0.5684	0.5552	0.5953	0.5809	0.5634	0.5531	0.6961	0.6906	0.6286	0.6272	0.5757	0.5699	0.5284	0.5264
			Hurricane	Other			0.2481	0.2307	0.2064	0.1993	0.2694	0.2556	0.2477	0.2412	0.2436	0.2312	0.2022	0.1972	0.2612	0.2508	0.2411	0.2369
				Wood	0.2620	0.2535	0.2330	0.2170	0.1947	0.1882	0.2525	0.2399	0.2326	0.2267	0.2288	0.2175	0.1908	0.1863	0.2450	0.2355	0.2265	0.2227
		Clips	None	Other			0.5842	0.5639	0.5422	0.5305	0.5817	0.5678	0.5311	0.5228	0.6091	0.5991	0.5345	0.5318	0.4979	0.4900	0.4111	0.4078
				Wood	0.6719	0.6576	0.5458	0.5269	0.5068	0.4961	0.5434	0.5306	0.4965	0.4889	0.5688	0.5596	0.4997	0.4972	0.4658	0.4585	0.3855	0.3824
			Hurricane	Other			0.2151	0.1934	0.1910	0.1828	0.2623	0.2478	0.2417	0.2356	0.2126	0.1947	0.1899	0.1836	0.2527	0.2412	0.2335	0.2288
				Wood	0.2283	0.2185	0.2039	0.1839	0.1816	0.1741	0.2477	0.2342	0.2286	0.2229	0.2016	0.1851	0.1806	0.1748	0.2388	0.2282	0.2211	0.2166
		Wraps	None	Other			0.5337	0.5144	0.4648	0.4559	0.4940	0.4819	0.4213	0.4158	0.4810	0.4675	0.3634	0.3583	0.3610	0.3504	0.2905	0.2861
				Wood	0.6148	0.5865	0.5030	0.4850	0.4386	0.4303	0.4659	0.4547	0.3980	0.3928	0.4538	0.4412	0.3439	0.3391	0.3416	0.3318	0.2757	0.2716
			Hurricane	Other			0.2090	0.1862	0.1859	0.1773	0.2586	0.2438	0.2384	0.2324	0.2052	0.1859	0.1834	0.1762	0.2473	0.2353	0.2293	0.2240
				Wood	0.2233	0.2128	0.1996	0.1783	0.1780	0.1700	0.2460	0.2321	0.2270	0.2214	0.1961	0.1780	0.1756	0.1689	0.2354	0.2242	0.2185	0.2136
	C	Toe Nails	None	Other			0.6569	0.6375	0.6126	0.5989	0.6405	0.6250	0.6094	0.5985	0.7534	0.7477	0.6767	0.6750	0.6243	0.6182	0.5688	0.5668
				Wood	0.7551	0.7375	0.6080	0.5902	0.5674	0.5548	0.5930	0.5788	0.5644	0.5545	0.6965	0.6913	0.6262	0.6246	0.5781	0.5725	0.5272	0.5254
			Hurricane	Other			0.2446	0.2301	0.2066	0.1999	0.2651	0.2532	0.2476	0.2415	0.2422	0.2306	0.2031	0.1981	0.2598	0.2502	0.2410	0.2367
				Wood	0.2591	0.2527	0.2298	0.2165	0.1949	0.1887	0.2486	0.2376	0.2325	0.2269	0.2275	0.2169	0.1917	0.1871	0.2437	0.2349	0.2264	0.2225
		Clips	None	Other			0.5801	0.5622	0.5438	0.5321	0.5837	0.5693	0.5275	0.5201	0.6052	0.5962	0.5357	0.5327	0.4922	0.4843	0.4106	0.4072
				Wood	0.6656	0.6517	0.5420	0.5254	0.5083	0.4975	0.5452	0.5320	0.4933	0.4864	0.5652	0.5569	0.5008	0.4981	0.4605	0.4533	0.3850	0.3819
			Hurricane	Other			0.2075	0.1894	0.1899	0.1820	0.2569	0.2438	0.2405	0.2341	0.2114	0.1953	0.1895	0.1832	0.2513	0.2408	0.2330	0.2287
				Wood	0.2222	0.2151	0.1970	0.1802	0.1806	0.1734	0.2427	0.2305	0.2275	0.2215	0.2005	0.1856	0.1802	0.1744	0.2375	0.2278	0.2206	0.2166
		Wraps	None	Other			0.5273	0.5097	0.4641	0.4553	0.4908	0.4784	0.4183	0.4126	0.4805	0.4684	0.3649	0.3599	0.3586	0.3493	0.2902	0.2859
				Wood	0.6129	0.5835	0.4970	0.4806	0.4380	0.4297	0.4629	0.4513	0.3952	0.3899	0.4533	0.4420	0.3453	0.3406	0.3394	0.3307	0.2754	0.2714
			Hurricane	Other			0.2015	0.1830	0.1849	0.1767	0.2522	0.2397	0.2366	0.2300	0.2019	0.1844	0.1826	0.1754	0.2452	0.2343	0.2288	0.2245
				Wood	0.2159	0.2082	0.1925	0.1753	0.1771	0.1694	0.2400	0.2282	0.2253	0.2192	0.1930	0.1765	0.1749	0.1682	0.2334	0.2232	0.2181	0.2141

Parapets and Rooftop Equipment. The results in Table 5-2 through Table 5-9 are for the case of no parapet and no RTE. Parapets can have a significant effect on reducing the extent and magnitude of negative pressures on a flat roof. As discussed in Section 3.6.1, wind tunnel test data have been used to model this effect. The parapets must be at least 6 feet in height to achieve the full benefit of the pressure reduction. Rooftop equipment (RTE) is vulnerable to wind damage, which adds to the losses for a building. RTE failures can also result in holes in the flat roof cover, thereby producing another path for water to enter the building.

We analyzed flat roof shape Group I buildings for 4 cases that cover the possibilities for the presence of parapets and inadequately-restrained rooftop equipment. We performed 72 simulations for each case. Table 5-10 summarizes the results of these simulations. Figure 5-1 also shows the resulting K_i factors for the possible cases of parapets and RTE for Group I buildings. Adequately-restrained RTE should be tested as "No" RTE in Table 5-10.

Table 5-10. Flat Roof Group I Parapet and RTE Secondary Factor K_i Values

Parapet and RTE Cases		*K_i Value*	
Parapet	*Inadequately-Restrained Rooftop Equipment*	*No SWR*	*SWR*
No	No	1.00	1.00
No	Yes	1.04	1.04
Yes	No	0.86	0.93
Yes	Yes	0.90	0.97

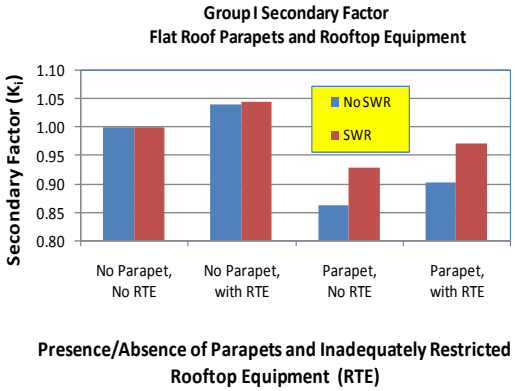


Figure 5-1. Effect of Parapets and Inadequately-Restrained RTE on Group I Buildings.

The Group I multi-family secondary factors are summarized in Table 5-11. This table is a similar to Table 4-15, except for the addition of parapets and RTE. The secondary factors are applied in the same manner as for single family houses using Equations (4-1), (4-2), and (4-3).

5.2.2 Post-FBC Construction

Wind loading provisions of the Florida Building Code (FBC) and effective dates of FBC code changes were summarized in Section 2.2.3. Two FBC construction eras were identified for the purposes of developing loss relativities for wind mitigation features:

1. FBC 2001 includes permit application dates of March 1, 2002 through December 7, 2006.
2. FBC 2006 includes permit applications on or after December 8, 2006.

There are several methods by which the FBC era can be determined and these are discussed in Section 2.2.4.8. There are many code amendments between these dates. The FBC 2006 date is significant since ring-shank nails, and soffit loads, and an option for 150 mph shingles were all introduced at that time. We designed buildings to the 2006 FBC and used our previous designs from the 2002 loss relativity study for the FBC 2001 designs.

Section 5.2.2.1 contains the Group I 2006 FBC loss relativities and Section 1 contains the 2001 FBC loss relativities.

Table 5-11. Multi-Family Group I Secondary Factors (K_i).

No.	*Secondary Factor Description*	*Can Apply to post-FBC era*	*Loss Relativity Multiplier (K_i)*	*Comments*
1	Dimensional Lumber Deck	Yes	0.96	Based on 2002 study. Applies to Deck C.
2	Unreinforced Masonry Walls	No	0.98	Based on 2002 study.
3	Reinforced Masonry Walls	Yes	0.95	Based on 2002 study; Secondary Factors 2 and 3 are mutually exclusive.
4	Opening Coverage – All Openings[1]	Yes Except not in HVHZ	0.98 Hurricane Only.	Based on 2002 study. Applies to Hurricane Protection Level; does not apply to other protection levels.
5	Unbraced Gable End	No	1.02	Based on 2002 study.
6	Foundation Restraint	No	Ter B: 1.38; Ter C: 1.54	Based on 2002 study.
7	Reinforced Concrete Roof Deck Integrate with Concrete or Reinforced Masonry Walls	Yes	DOES NOT APPLY.	Group I Buildings with reinforced concrete roof decks should be treated as Group II Buildings.
8	Enhanced Wood Panel Roof Deck (≥ 5/8 " plywood)	Yes	0.99	HSRS (Secondary Factor 1 and 8 are mutually exclusive.) Applies to Deck C.
9	Shutter Interpolation Between None and Hurricane	Yes	Ordinary: Terrain B S = 0.72, Terrain C S = 0.56; OSB: S = 0.72, S = 0.56; Plywood: S = 0.48, S = 0.46; Basic: S = 0.23, S = 0.19	Based on 2003-2004 DCA Shutter Impact Tests for OSB and Plywood. Values given are shutter interpolation factors (S).
10	Vinyl Siding	Yes	1.02	Based on HSRS study.
11	Window, Door, and Skylight Water Leak Potential[2] Total Number of Openings	Yes	Other / Non-Porous Shutters: a. Casement and Fixed: 0: 1.00 / 1.00; 1 to 10: 1.03 / 1.01; 11 to 20: 1.05 / 1.03; 21 to 30: 1.08 / 1.06; ≥ 31: 1.11 / 1.09. b. All Other Window/Door Types: 0: 1.00 / 1.00; 1 to 10: 1.04 / 1.02; 11 to 20: 1.07 / 1.04; 21 to 30: 1.11 / 1.08; ≥ 31: 1.14 / 1.11	Based on new sensitivity study. Count the number of openings in each category. All doors are counted as other type. Determine the appropriate factor for each type and multiply the factors together.
12	Double Wrap Roof-to-Wall Connector	No	Opening Prot. / Terrain B / Terrain C: Other: 0.98 / 0.93; Basic, Hurricane: 0.99 / 0.97	Based on new sensitivity study. Does not apply to post-FBC.
13	Roof Cover Age Interpolation	Yes	Type / A(yrs): Tile, Cement, Slate, Metal: 40; Other: 25	Use Equation (4- 3a) to interpolate from FBC to non-FBC Roof Cover. (N=Age of roof cover in years.)
14	Partially Enclosed Designs	Yes	0.98	Applies to post-FBC era, partially enclosed designs in WBD region. Apply to "Opening Protection = None."
15	Parapets and Roof Top Equipment		Use Table 5-10	Based on new sensitivity study.

[1] All openings protected factor shall only be used when all openings (including non-glazed) are protected to "Hurricane."

[2] Each sliding glass door is counted as 4 openings in determining the total number of openings. All other openings (doors, windows and skylights) are counted as one each.

5.2.2.1 2006 FBC Group I Construction

We developed new designs for the Group I buildings for each Florida wind zone (100 mph to 150 mph). Similar to the single family approach, we performed consistency checks with the Group I pre-FBC relativities. These consistency checks controlled the mapping of the post-FBC construction into the pre-FBC tables. Hence, similar to the single family post-FBC relativities, there are errors in the post-FBC Group I construction relativities resulting from the use of a single pre-FBC table for Group I buildings.

FBC 2006 Group I Loss Relativities. The loss relativities for Group I Buildings constructed to the 2006 FBC are given in Table 5-12 and Table 5-13 for Terrains B and C, respectively. These relativities reflect the consistency constraint of mapping the building features into the pre-FBC Group I statewide relativities. These relativities match the strongest features of the pre-FBC tables and the lowest relativities are slightly lower than the lowest relativity in Table 5-6 through Table 5-9.

Secondary Factors Regarding secondary factors for Group I FBC 2006 construction, the following notes apply:

1. Factor 1 or Factor 8 can be applied if the wood deck is dimensional lumber or enhanced (See Appendix A).
2. Factor 3 applies to Group I Residences with reinforced masonry walls.
3. The HVHZ relativities reflect the fact that all openings are protected and, hence, there is no need to apply Secondary Factor 4 to the HVHZ results. Secondary Factor 4 can be applied to non-HVHZ locations if all openings are protected to "Hurricane" level.
4. If the opening protection is provided by wood panel shutters, use the interpolation approach given by Equation (4-2) and the factors (Secondary Factor 9) in Table 5-11.
5. If the building has vinyl siding, apply Secondary Factor 10 in Table 5-11.
6. The leak potential factor (Secondary Factor 11 in Table 5-11) for windows, doors, and skylights should be applied to FBC 2006 buildings.
7. Double-wrap factor does not apply to post-FBC Group I.
8. Roof cover age interpolation is appropriate for post-FBC.
9. If the building has a reinforced concrete roof deck, use the Group II relativity tables.
10. If the building has Secondary Water Resistance (SWR), which meets the requirements in Appendix A, apply the appropriate factor from Table 5-14 or Table 5-15. We note that few FBC buildings are built with self adhering SWR and hence, this factor will rarely be applied to post-FBC residences.

5.2.2.2 2001 FBC Group I Construction

The FBC 2001 Group I loss relativities were developed by simulating the FBC 2001 designs developed in the 2002 loss relativity study to the updated hurricane wind hazard model results summarized in Section 2.3.6.

Table 5-16 (Terrain B) and Table 5-17 (Terrain C) contain the loss relativities for Group I buildings built to the FBC 2001. Table 5-18 and Table 5-19 contain the SWR secondary factors for these buildings. The application of these factors and other secondary factors follows the same approach as illustrated previously. Since the FBC 2001 did not include requirements for soffit design pressures, the Group I FBC 2001 tables include wood and other soffits.

We note that the FBC tables and the SWR tables contain all the information needed for mitigation factors (for designs beyond the FBC minimal requirements) for opening protection and applying SWR.

Table 5-12. Terrain B FBC 2006 Multifamily Group I Buildings

Terrain B Group I 2006 FBC [1, 2]			Flat	Low Roof Slope (≤ 5:12)				Other Roof slope (≥ 6:12)			
			Built-Up	Non-Tile		Tile		Non-Tile		Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection		Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[3]	100	None	0.4658	0.3466	0.3060	0.3801	0.3430	0.3310	0.2797	0.3462	0.3120
		Hurricane[5]	0.3422	0.2575	0.2405	0.3268	0.3058	0.2569	0.2388	0.3191	0.2975
	110	None	0.4564	0.3396	0.2998	0.3725	0.3361	0.3244	0.2741	0.3392	0.3057
		Hurricane[6]	0.3353	0.2523	0.2356	0.3202	0.2996	0.2517	0.2339	0.3127	0.2915
	≥ 120	None[7]	0.4519	0.3362	0.2968	0.3687	0.3327	0.3211	0.2714	0.3358	0.3026
		Hurricane	0.3319	0.2497	0.2333	0.3170	0.2966	0.2492	0.2316	0.3095	0.2885
Non-FBC[4]	100	None	0.8308	0.6113	0.5307	0.6209	0.5517	0.5505	0.4463	0.5387	0.4775
		Hurricane	0.6499	0.4835	0.4349	0.5492	0.4992	0.4528	0.3965	0.5066	0.4657
	110	None	0.8140	0.5990	0.5200	0.6084	0.5406	0.5393	0.4372	0.5278	0.4678
		Hurricane	0.6367	0.4738	0.4261	0.5381	0.4891	0.4436	0.3885	0.4963	0.4563
	≥ 120	None	0.8059	0.5930	0.5148	0.6023	0.5352	0.5340	0.4329	0.5226	0.4631
		Hurricane	0.6303	0.4690	0.4218	0.5327	0.4842	0.4391	0.3846	0.4913	0.4516

[1] Refer to discussion in Section 2.2.4.8 and Figure 4-7 to determine whether or not FBC 2001 or FBC 2006 relativity tables should be used for FBC 2006 construction.

[2] Use Table 5-20 for FBC 2006 Group I Buildings with reinforced concrete roof deck.

[3] FBC Roof Covers (apply this part of the table with no roof cover age interpolation for 2006 FBC roof covers less than or equal to 5 years old).

[4] Non FBC Roof Covers (this part of the table is used with FBC Roof Covers to interpolate for 2006 FBC construction with roof covers 6 years old or more). See Section 4.2.5.

[5] Opening Protection is not required by the 2006 FBC for 100 mph design windspeeds. Hence, this row only applies to 2006 FBC Group I Buildings that are further mitigated with opening protection.

[6] Opening protection is required within 1 mile of coast for 110 mph design windspeeds. For most locations in Florida in the 110 mph windzone, this row only applies to 2006 FBC Group I Buildings mitigated with opening protection.

[7] This row is included only for interpolation of shutters less than "Hurricane" level of protection per Table 5-11.

Table 5-13. Terrain C 2006 FBC Multifamily Group I Buildings

Terrain C Group I FBC 2006[1,2]			Flat	Low Roof Slope (≤ 5:12)				Other Roof slope (≥ 6:12)			
			Built-Up	Non-Tile		Tile		Non-Tile		Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection		Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[3]	100	None	0.6129	0.4970	0.4380	0.4629	0.3952	0.4533	0.3453	0.3394	0.2754
		Hurricane[5]	0.2159	0.1925	0.1771	0.2400	0.2253	0.1930	0.1749	0.2334	0.2181
	110	None	0.5947	0.4822	0.4250	0.4491	0.3834	0.4398	0.3350	0.3293	0.2672
		Hurricane[6]	0.2095	0.1868	0.1718	0.2328	0.2186	0.1872	0.1697	0.2265	0.2116
	≥ 120	None[7]	0.5881	0.4769	0.4203	0.4442	0.3792	0.4350	0.3313	0.3257	0.2643
		Hurricane	0.2095	0.1868	0.1718	0.2328	0.2186	0.1872	0.1697	0.2265	0.2116
	HVHZ[8]	Hurricane	0.2011	0.1793	0.1649	0.2235	0.2099	0.1797	0.1629	0.2174	0.2031
Non-FBC[4]	100	None	0.9039	0.7397	0.7152	0.6980	0.6192	0.6448	0.5165	0.4889	0.4074
		Hurricane	0.3928	0.3534	0.3185	0.3997	0.3741	0.3261	0.2853	0.3706	0.3462
	110	None	0.8770	0.7176	0.6939	0.6772	0.6008	0.6256	0.5011	0.4743	0.3953
		Hurricane	0.3811	0.3429	0.3090	0.3878	0.3630	0.3164	0.2768	0.3596	0.3359
	≥ 120	None	0.8674	0.7097	0.6863	0.6697	0.5942	0.6187	0.4956	0.4691	0.3909
		Hurricane	0.3811	0.3429	0.3090	0.3878	0.3630	0.3164	0.2768	0.3596	0.3359
	HVHZ	Hurricane	0.3658	0.3292	0.2966	0.3723	0.3485	0.3038	0.2657	0.3452	0.3225

[1] Refer to discussion in Section 2.2.4.8 and Figure 4-7 to determine whether or not FBC 2001 or FBC 2006 relativity tables should be used for FBC 2006 construction.

[2] Use Table 5-21 for FBC 2006 Group I Buildings with reinforced concrete roof deck.

[3] FBC Roof Covers (apply this part of the table with no roof cover age interpolation for 2006 FBC roof covers less than or equal to 5 years old).

[4] Non FBC Roof Covers (this part of the table is used with FBC Roof Covers to interpolate for 2006 FBC construction with roof covers 6 years old or more). See Section 4.2.5.

[5] Opening Protection is not required by the 2006 FBC for 100 mph design windspeeds. Hence, this row only applies to 2006 FBC Group I Buildings that are further mitigated with opening protection.

[6] Opening protection is required within 1 mile of coast for 110 mph design windspeeds. For most locations in Florida in the 110 mph windzone, this row only applies to 2006 FBC Group I Buildings mitigated with opening protection.

[7] This row is included only for interpolation of shutters less than "Hurricane" level of protection per Table 5-11.

[8] Secondary Factor 4 (All Openings Protected) has already been considered for HVHZ.

FBC 2001 Partially Enclosed Designs. The 2001 FBC allowed for partially-enclosed designs in the WBD region. Partially enclosed designs do not provide opening protection for wind-borne debris. Although the building is designed for internal pressures, it still has unprotected glazing and hence is subject to higher losses than a building with opening protection.

The relativities for partially-enclosed designs are determined by using the no opening protection values in Table 5-16 and Table 5-17. With a secondary factor of 0.98. This factor accounts for the

increased pressure resistance of the windows, doors, and other components due to the internal pressure design requirement.

Table 5-14. Terrain B Secondary Water Resistance Factors for Group I 2006 FBC

Terrain B Group I FBC 2006 SWR[1]			Flat	Low Roof Slope (≤ 5:12)				Other Roof slope (≥ 6:12)			
			Built-Up	Non-tile		Tile		Non-tile		Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection		Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100, 110	None	0.956	0.959	0.984	0.984	0.991	0.968	0.986	0.978	0.992
	≥120	Hurricane	0.950	0.944	0.978	0.978	0.987	0.949	0.983	0.975	0.990
Non-FBC[3]	100, 110	None	0.748	0.751	0.792	0.855	0.888	0.780	0.840	0.875	0.928
	≥120	Hurricane	0.741	0.736	0.797	0.854	0.901	0.773	0.858	0.881	0.934

[1] These SWR factors must be determined by separate inspection or affadavit. SWR is not required by the FBC and is not typical of new construction.

[2] FBC roof covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

[3] Non-FBC roof covers (this part of the table is used with FBC to interpolate for 2001 FBC construction with roof covers 6 years old or more). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

Table 5-15. Terrain C Secondary Water Resistance Factors for Group I 2006 FBC

Terrain C Group I FBC 2006 SWR[1]			Flat	Low Roof Slope (≤ 5:12)				Other Roof slope (≥ 6:12)			
			Built-Up	Non-tile		Tile		Non-tile		Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection		Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100, 110	None	0.952	0.967	0.981	0.975	0.987	0.975	0.987	0.974	0.986
	≥120[4]	Hurricane	0.964	0.911	0.956	0.951	0.973	0.915	0.962	0.956	0.982
Non-FBC[3]	100, 110	None	0.771	0.757	0.735	0.825	0.837	0.799	0.796	0.856	0.881
	≥120	Hurricane	0.777	0.668	0.735	0.810	0.854	0.724	0.806	0.849	0.903

[1] These SWR factors must be determined by separate inspection or affadavit. SWR is not required by the FBC and is not typical of new construction.

[2] FBC roof covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

[3] Non-FBC roof covers (this part of the table is used with FBC to interpolate for 2001 FBC construction with roof covers 6 years old or more). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

[4] Use this row also for HVHZ.

Table 5-16. Terrain B FBC 2001 Multifamily Group I Buildings

Terrain B Group I FBC 2001[1]				Flat	Low Roof Slope (≤ 5:12)				Other Roof slope (≥ 6:12)			
				Built-Up	Non-Tile		Tile		Non-Tile		Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Soffits[7]		Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100, 110	None	Other		0.3971	0.3462	0.4345	0.3886	0.3812	0.3169	0.3918	0.3533
			Wood	0.4728	0.3545	0.3091	0.3880	0.3470	0.3404	0.2829	0.3498	0.3154
		Hurricane[4,5]	Other		0.2954	0.2723	0.3728	0.3474	0.2932	0.2688	0.3611	0.3364
			Wood	0.3493	0.2638	0.2431	0.3329	0.3101	0.2618	0.2422	0.3224	0.3016
	≥120	None[6]	Other		0.3931	0.3427	0.4302	0.3847	0.3774	0.3137	0.3878	0.3497
			Wood	0.4680	0.3510	0.3060	0.3841	0.3435	0.3370	0.2801	0.3463	0.3123
		Hurricane	Other		0.2925	0.2696	0.3691	0.3439	0.2903	0.2661	0.3574	0.3331
			Wood	0.3458	0.2612	0.2407	0.3296	0.3070	0.2592	0.2398	0.3191	0.2986
Non-FBC[3]	100, 110	None	Other		0.6893	0.5878	0.7032	0.6209	0.6101	0.4907	0.5979	0.5352
			Wood	0.8384	0.6338	0.5425	0.6421	0.5672	0.5760	0.4556	0.5529	0.4912
		Hurricane	Other		0.5502	0.4927	0.6325	0.5733	0.5109	0.4473	0.5776	0.5313
			Wood	0.6549	0.4986	0.4447	0.5697	0.5163	0.4697	0.4111	0.5226	0.4821
	≥120	None	Other		0.6824	0.5819	0.6962	0.6147	0.6040	0.4858	0.5919	0.5298
			Wood	0.8300	0.6275	0.5371	0.6357	0.5616	0.5702	0.4510	0.5474	0.4863
		Hurricane	Other		0.5447	0.4877	0.6262	0.5676	0.5058	0.4428	0.5718	0.5259
			Wood	0.6483	0.4936	0.4403	0.5640	0.5112	0.4650	0.4070	0.5174	0.4773

[1] Use Table 5-20 for FBC 2001 Group I Buildings with reinforced concrete roof deck.

[2] FBC Roof Covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old).

[3] Non FBC Roof Covers (this part of the table is used with FBC Roof Covers to interpolate for 2001 FBC construction with roof covers 6 years old or more). See Section 4.2.5.

[4] Opening Protection is not required by the 2001 FBC for 100 mph design windspeeds. Hence, this row only applies to 2001 FBC Group I Buildings that are further mitigated with opening protection.

[5] Opening protection is required within 1 mile of coast for 110 mph design windspeeds. For most locations in Florida in the 110 mph windzone, this row only applies to 2001 FBC Group I Buildings mitigated with opening protection.

[6] This row included for: (a) Panhandle WBD exception; (b) interpolation of shutters less than "Hurricane" per Table 5-11; and (c) partially enclosed designs in the WBDR. Apply a factor of 0.98 to the row for partially enclosed designs, per Table 4-15.

[7] Use wood soffit row for the use of this table for any FBC 2006 construction.

Table 5-17. Terrain C FBC 2001 Multifamily Group I Buildings

Terrain B Group I FBC 2001[1]				Flat	Low Roof Slope (≤ 5:12)				Other Roof slope (≥ 6:12)			
				Built-Up	Non-Tile		Tile		Non-Tile		Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Soffits[7]		Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100, 110	None	Other		0.5337	0.4648	0.4940	0.4213	0.4810	0.3634	0.3610	0.2905
			Wood	0.6148	0.5030	0.4386	0.4659	0.3980	0.4538	0.3439	0.3416	0.2757
		Hurricane[4, 5]	Other		0.2090	0.1859	0.2586	0.2384	0.2052	0.1834	0.2473	0.2293
			Wood	0.2233	0.1996	0.1780	0.2460	0.2270	0.1961	0.1756	0.2354	0.2185
	≥120	None[6]	Other		0.5220	0.4595	0.4859	0.4141	0.4757	0.3612	0.3551	0.2872
			Wood	0.6068	0.4921	0.4336	0.4583	0.3912	0.4488	0.3418	0.3360	0.2727
		Hurricane	Other		0.1994	0.1831	0.2497	0.2342	0.1999	0.1807	0.2428	0.2265
			Wood	0.2137	0.1906	0.1753	0.2376	0.2231	0.1910	0.1731	0.2311	0.2159
	HVHZ[8]	Hurricane	Other		0.1955	0.1794	0.2447	0.2295	0.1959	0.1771	0.2379	0.2220
			Wood	0.2095	0.1868	0.1718	0.2328	0.2186	0.1872	0.1697	0.2265	0.2116
Non-FBC[3]	100, 110	None	Other		0.7710	0.7106	0.7112	0.6258	0.6560	0.5083	0.4971	0.4077
			Wood	0.8947	0.7395	0.7034	0.6924	0.6141	0.6419	0.5119	0.4920	0.4052
		Hurricane	Other		0.3546	0.3171	0.4131	0.3797	0.3225	0.2788	0.3716	0.3447
			Wood	0.4005	0.3616	0.3184	0.4131	0.3757	0.3315	0.2881	0.3742	0.3470
	≥120	None	Other		0.7673	0.7156	0.7119	0.6239	0.6507	0.5059	0.4900	0.4051
			Wood	0.8940	0.7323	0.7081	0.6910	0.6130	0.6384	0.5113	0.4840	0.4033
		Hurricane	Other		0.3488	0.3137	0.4036	0.3757	0.3141	0.2755	0.3646	0.3403
			Wood	0.3884	0.3499	0.3153	0.3957	0.3704	0.3229	0.2825	0.3669	0.3428
	HVHZ	Hurricane	Other		0.3418	0.3074	0.3956	0.3682	0.3078	0.2700	0.3574	0.3335
			Wood	0.3807	0.3429	0.3090	0.3878	0.3630	0.3164	0.2768	0.3596	0.3359

[1] Use Table 5-21 for FBC 2001 Group I Buildings with reinforced concrete roof deck.

[2] FBC Roof Covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old).

[3] Non FBC Roof Covers (this part of the table is used with FBC Roof Covers to interpolate for 2001 FBC construction with roof covers 6 years old or more). See Section 4.2.5.

[4] Opening Protection is not required by the 2001 FBC for 100 mph design windspeeds. Hence, this row only applies to 2001 FBC Group I Buildings that are further mitigated with opening protection.

[5] Opening protection is required within 1 mile of coast for 110 mph design windspeeds. For most locations in Florida in the 110 mph windzone, this row only applies to 2001 FBC Group I Buildings mitigated with opening protection.

[6] This row included for: (a) Panhandle WBD exception; (b) interpolation of shutters less than "Hurricane" per Table 5-11; and (c) partially enclosed designs in the WBDR. Apply a factor of 0.98 to the row for partially enclosed designs, per Table 4-15.

[7] Use wood soffit row for the use of this table for any FBC 2006 construction.

[8] Secondary Factor 4 (All openins protected) have already been considered in the HVHZ.

Table 5-18. Terrain B Secondary Water Resistance Factors for Group I 2001 FBC

Terrain B Group I FBC 2001 SWR[1]				Flat	Low Roof Slope (≤ 5:12)				Other Roof slope (≥ 6:12)			
				Built-Up	Non-tile		Tile		Non-tile		Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Soffit		Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100, 110	None	Other		0.947	0.978	0.973	0.988	0.957	0.986	0.977	0.990
			Wood	0.950	0.950	0.983	0.973	0.988	0.957	0.986	0.977	0.991
	≥120	Hurricane	Other		0.936	0.973	0.971	0.983	0.950	0.985	0.978	0.987
			Wood	0.950	0.942	0.984	0.971	0.983	0.950	0.985	0.978	0.990
Non-FBC[3]	100, 110	None	Other		0.724	0.787	0.845	0.886	0.774	0.838	0.875	0.924
			Wood	0.724	0.731	0.794	0.851	0.885	0.774	0.840	0.876	0.924
	≥120	Hurricane	Other		0.715	0.789	0.841	0.892	0.765	0.844	0.878	0.926
			Wood	0.727	0.728	0.806	0.845	0.897	0.777	0.857	0.885	0.934

[1] These SWR factors must be determined by separate inspection or affadavit. SWR is not required by the FBC and is not typical of new construction.

[2] FBC roof covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

[3] Non-FBC roof covers (this part of the table is used with FBC to interpolate for 2001 FBC construction with roof covers 6 years old or more). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

Partially enclosed designs are not allowed in the HVHZ and, hence, these factors do not apply to the HVHZ.

Consideration of 2001 Panhandle WBD Region Exemption. The 2001 FBC had an exemption for the Florida Panhandle for the WBD requirements for the buildings more than one mile from the coast. Therefore, Group I buildings built in the Panhandle to the 2001 FBC more than 1 mile from the coast and in a ≥ 120 mph wind zone may not have WBD protection. The loss relativities for these buildings should be determined by using the no shutter results for buildings built without opening protection under the Panhandle WBD exception.

Table 5-19. Terrain C Secondary Water Resistance Factors for Group I 2001 FBC

Terrain C Group I FBC 2001 SWR[1]				Flat	Low Roof Slope (≤ 5:12)				Other Roof slope (≥ 6:12)			
				Built-Up	Non-tile		Tile		Non-tile		Tile	
Roof Cover	FBC Windspeed (mph)	Opening Protection	Soffit		Other	Hip	Other	Hip	Other	Hip	Other	Hip
FBC[2]	100, 110	None	Other		0.927	0.967	0.959	0.981	0.939	0.973	0.961	0.981
			Wood	0.954	0.929	0.968	0.960	0.981	0.940	0.974	0.962	0.981
	≥120	Hurricane	Other		0.909	0.955	0.950	0.972	0.913	0.961	0.956	0.981
			Wood	0.964	0.911	0.956	0.951	0.973	0.915	0.962	0.956	0.982
Non-FBC[3]	100, 110	None	Other		0.720	0.731	0.813	0.836	0.773	0.802	0.851	0.888
			Wood	0.739	0.727	0.724	0.814	0.833	0.771	0.786	0.846	0.880
	≥120	Hurricane	Other		0.652	0.715	0.789	0.837	0.712	0.789	0.838	0.897
			Wood	0.699	0.667	0.735	0.805	0.854	0.725	0.804	0.849	0.903

[1] These SWR factors must be determined by separate inspection or affadavit. SWR is not required by the FBC and is not typical of new construction.

[2] FBC roof covers (apply this part of the table with no roof cover age interpolation for 2001 FBC roof covers less than or equal to 5 years old). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

[3] Non-FBC roof covers (this part of the table is used with FBC to interpolate for 2001 FBC construction with roof covers 6 years old or more). The SWR factor must be applied as part of the FBC roof cover age interpolation (Eq. 4-3) and not as a separate factor per Eq. 4-1(b).

5.3 Group II Buildings

Group II MF residential buildings are structures that are 60 feet or less in height with non-wood roof decks. The typical roof deck types for Group II buildings are concrete or metal roof decks. The three construction eras modeled in the analysis of Group II buildings are:

1. 1982 or earlier, for which buildings designed to 1976 Standard Building Code (SBC 1976) are assumed to be typical.
2. 1983 through February 28, 2002, for which buildings designed to the 1988 Standard Building Code (SBC 1988) are assumed to be typical.
3. March 1, 2002 and later, for which buildings designed to the provisions of the 2001 Florida Building Code (FBC 2001) are assumed to be typical.

Both the building code era and visual inspection are required to determine the proper loss relativity.

5.3.1 Group II Loss Relativity Tables

The Group II loss relativity data for a 2% deductible (as a percentage of building replacement value) are given in Table 5-20 and Table 5-21 for Terrains B and C, respectively. To use these tables, one must obtain the following information:

1. The exposure category: Terrain B or Terrain C. Use the definitions given in Section A.1.1.1 of Appendix A. Note that the determination of the terrain type for the purposes of determining loss relativities for Group II buildings does not depend on whether the building is within the High Velocity Hurricane Zone (HVHZ).
2. The basic wind speed zone. Use the 2007 revision to FBC 2004 Figure 1609 or simply the county if the building is located in Broward, Miami-Dade, or Monroe County.
3. The design code era: SBC 1976, SBC 1988, or FBC 2001. If the design code era is FBC 2001 and the building is located in the Wind Borne Debris Region (WBDR), then the FBC 2001 design option is also required (Partially Enclosed or Enclosed). Note that the Partially Enclosed design option was removed from the FBC effective July 1, 2007.

Table 5-20. Group II Relativities for Terrain B

					Metal Roof Deck				Concrete	
					Non-FBC Equivalent Roof Covering		FBC Equivalent Roof Covering		Non-FBC Equiv. Roof Cover	FBC Equiv. Roof Cover
Actual Terrain	FBC Wind Speed	Model Design Code	FBC 2001 Design Option	Protection	No SWR	SWR	No SWR	SWR		
B	< = 100	SBC 1976 (Pre 1983)		None	**1.0000**	0.6902	0.7263	0.6695	0.4862	0.4670
				Hurricane	0.6578	0.3805	0.4069	0.3552	0.3159	0.2945
		SBC 1988 (1983-2001)		None	0.6281	0.4142	0.4328	0.3875	0.3331	0.3132
				Hurricane	0.4876	0.3499	0.3532	0.3225	0.3118	0.2900
		FBC 2001 (2002-present)	Enclosed	None			0.4144	0.3774		0.2354
				Hurricane			0.2373	0.2281		0.1860
	101-110	SBC 1976 (Pre 1983)		None	**1.0000**	0.6324	0.6820	0.6093	0.5001	0.4771
				Hurricane	0.7880	0.4427	0.4852	0.4161	0.3970	0.3710
		SBC 1988 (1983-2001)		None	0.7244	0.4695	0.5022	0.4465	0.4061	0.3866
				Hurricane	0.5971	0.4257	0.4346	0.3964	0.3911	0.3646
		FBC 2001 (2002-present)	Enclosed	None			0.4528	0.4062		0.3221
				Hurricane			0.3463	0.3216		0.2869
	111-120	SBC 1976 (Pre 1983)		None	**1.0000**	0.6580	0.7159	0.6395	0.5030	0.4850
				Hurricane	0.7616	0.4366	0.4914	0.4163	0.3862	0.3657
		SBC 1988 (1983-2001)		None	0.7168	0.4691	0.5137	0.4515	0.3968	0.3818
				Hurricane	0.5837	0.4151	0.4346	0.3920	0.3797	0.3590
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.4276	0.3771		0.3346
				Hurricane			0.3830	0.3399		0.3135
	121-130	SBC 1976 (Pre 1983)		None	**1.0000**	0.6457	0.7257	0.6273	0.5163	0.5016
				Hurricane	0.8175	0.4689	0.5526	0.4486	0.4118	0.3957
		SBC 1988 (1983-2001)		None	0.8882	0.5816	0.6627	0.5685	0.4803	0.4663
				Hurricane	0.7071	0.4985	0.5539	0.4813	0.4506	0.4330
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.5340	0.4560		0.4127
				Hurricane			0.4815	0.4222		0.3929
	131-140	SBC 1976 (Pre 1983)		None	**1.0000**	0.6590	0.7318	0.6399	0.5675	0.5514
				Hurricane	0.7482	0.5114	0.5622	0.4921	0.4517	0.4382
		SBC 1988 (1983-2001)		None	0.9696	0.6641	0.7405	0.6553	0.5012	0.4888
				Hurricane	0.7560	0.5233	0.5801	0.5099	0.4535	0.4388
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.5904	0.4980		0.4602
				Hurricane			0.5336	0.4603		0.4301
	Broward	SBC 1976 (Pre 1983)		None	**1.0000**	0.6520	0.7638	0.6432	0.5621	0.5517
				Hurricane	0.7813	0.5285	0.5985	0.5076	0.4738	0.4571
		SBC 1988 (1983-2001)		None	0.9460	0.6334	0.7243	0.6207	0.5005	0.4871
				Hurricane	0.7441	0.5256	0.5910	0.5105	0.4617	0.4452
		FBC 2001	Enclosed	Hurricane			0.5180	0.4484		0.4287
	Miami-Dade	SBC 1976 (Pre 1983)		None	**1.0000**	0.6577	0.7704	0.6485	0.5606	0.5506
				Hurricane	0.7737	0.5237	0.5978	0.5045	0.4644	0.4485
		SBC 1988 (1983-2001)		None	0.9441	0.6379	0.7304	0.6261	0.4940	0.4813
				Hurricane	0.7382	0.5224	0.5906	0.5080	0.4513	0.4357
		FBC 2001	Enclosed	Hurricane			0.5250	0.4521		0.4263
	Monroe	SBC 1976 (Pre 1983)		None	**1.0000**	0.6861	0.8015	0.6739	0.5541	0.5459
				Hurricane	0.7465	0.5091	0.5947	0.4933	0.4259	0.4128
		SBC 1988 (1983-2001)		None	0.9374	0.6623	0.7585	0.6518	0.4691	0.4578
				Hurricane	0.7150	0.5116	0.5880	0.4999	0.4067	0.3943
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.6269	0.5041		0.4351
				Hurricane			0.5471	0.4568		0.3927

Table 5-21. Group II Relativities for Terrain C

					Metal Roof Deck				Concrete	
					Non-FBC Equivalent		FBC Equivalent		Non-FBC Equiv. Roof Cover	FBC Equiv. Roof Cover
Actual Terrain	FBC Wind Speed	Model Design Code	FBC 2001 Design Option	Protection	No SWR	SWR	No SWR	SWR		
C	< = 100	SBC 1976 (Pre 1983)		None	**1.0000**	0.7695	0.8053	0.7482	0.4660	0.4509
				Hurricane	0.4496	0.2949	0.3106	0.2727	0.2183	0.2004
		SBC 1988 (1983-2001)		None	0.5903	0.4056	0.4351	0.3861	0.2702	0.2548
				Hurricane	0.3889	0.2528	0.2659	0.2326	0.2102	0.1934
		FBC 2001 (2002-present)	Enclosed	None			0.3126	0.2737		0.1499
				Hurricane			0.1832	0.1633		0.1202
	101-110	SBC 1976 (Pre 1983)		None	**1.0000**	0.6966	0.7481	0.6749	0.4642	0.4453
				Hurricane	0.5748	0.3643	0.3949	0.3403	0.3032	0.2808
		SBC 1988 (1983-2001)		None	0.6678	0.4135	0.4559	0.3917	0.3307	0.3100
				Hurricane	0.5242	0.3360	0.3622	0.3115	0.2963	0.2741
		FBC 2001 (2002-present)	Enclosed	None			0.3843	0.3244		0.2303
				Hurricane			0.2946	0.2565		0.2104
	111-120	SBC 1976 (Pre 1983)		None	**1.0000**	0.7260	0.7858	0.7107	0.4664	0.4521
				Hurricane	0.5615	0.3595	0.4018	0.3423	0.2900	0.2734
		SBC 1988 (1983-2001)		None	0.6603	0.4215	0.4747	0.4051	0.3225	0.3070
				Hurricane	0.5070	0.3252	0.3624	0.3072	0.2827	0.2657
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.3312	0.2710		0.2367
				Hurricane			0.2931	0.2422		0.2278
	121-130	SBC 1976 (Pre 1983)		None	**1.0000**	0.6917	0.7740	0.6738	0.4739	0.4603
				Hurricane	0.6463	0.4133	0.4841	0.3962	0.3346	0.3195
		SBC 1988 (1983-2001)		None	0.8513	0.5423	0.6335	0.5247	0.4179	0.4023
				Hurricane	0.6753	0.4364	0.5137	0.4177	0.3750	0.3603
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.4520	0.3610		0.3257
				Hurricane			0.4123	0.3411		0.3149
	131-140	SBC 1976 (Pre 1983)		None	**1.0000**	0.6462	0.7463	0.6286	0.4994	0.4826
				Hurricane	0.7481	0.4619	0.5567	0.4448	0.3896	0.3754
		SBC 1988 (1983-2001)		None	0.9995	0.7188	0.8040	0.6978	0.5007	0.4844
				Hurricane	0.7478	0.4787	0.5668	0.4680	0.3841	0.3711
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.5150	0.4116		0.3893
				Hurricane			0.4853	0.3891		0.3635
	Broward	SBC 1976 (Pre 1983)		None	**1.0000**	0.6203	0.7455	0.6030	0.5002	0.4865
				Hurricane	0.7749	0.4743	0.5780	0.4572	0.4082	0.3932
		SBC 1988 (1983-2001)		None	0.9420	0.6176	0.7216	0.6019	0.4599	0.4450
				Hurricane	0.7362	0.4797	0.5717	0.4626	0.3993	0.3856
		FBC 2001	Enclosed	Hurricane			0.4898	0.3956		0.3620
	Miami-Dade	SBC 1976 (Pre 1983)		None	**1.0000**	0.6280	0.7553	0.6121	0.4995	0.4867
				Hurricane	0.7709	0.4738	0.5807	0.4572	0.4020	0.3878
		SBC 1988 (1983-2001)		None	0.9470	0.6288	0.7349	0.6143	0.4605	0.4464
				Hurricane	0.7336	0.4800	0.5752	0.4644	0.3928	0.3797
		FBC 2001	Enclosed	Hurricane			0.4944	0.4024		0.3649
	Monroe	SBC 1976 (Pre 1983)		None	**1.0000**	0.6633	0.7909	0.6504	0.4975	0.4861
				Hurricane	0.7548	0.4739	0.5908	0.4588	0.3751	0.3634
		SBC 1988 (1983-2001)		None	0.9687	0.6808	0.7885	0.6695	0.4671	0.4546
				Hurricane	0.7221	0.4835	0.5868	0.4719	0.3634	0.3524
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.5451	0.4135		0.3779
				Hurricane			0.5033	0.3938		0.3481

The data listed in Table 5-20 and Table 5-21 represent the relativities obtained at a representative location within each FBC basic wind speed zone. For each unique combination of terrain category and FBC basic wind speed zone, the loss costs have been normalized to the SBC 1976 building with no opening protection, a non-FBC equivalent roof cover, no secondary water resistance, a non-concrete roof deck, no parapet, and no inadequately restrained rooftop equipment present. This building has been selected arbitrarily and the tables can be easily re-normalized by any other building type. A key point in the use of the tables is that they have been normalized within each terrain category and wind speed zone. The user determines the terrain category and wind speed zone using the one set of definitions, regardless of the year built.

As an example of how to use these tables, consider the case of a four-story condominium building built in 1990 in Terrain B in Orlando. The building is reinforced concrete with a reinforced concrete roof deck and non-FBC equivalent roof cover. The building has no opening protection. Since the building was built in 1990, we use the SBC 1988 relativities. The FBC design windspeed for Orlando is 110 mph. Therefore, we find the loss relativity to be 0.4061. This means that for 2% deductible (as a percentage of building replacement value) that the loss costs are 59% less than that of the reference SBC 1976 non-concrete deck building at that location.

Table 5-20 and Table 5-21 are based on minimal load designs for each building code era. Over design is not considered. The only exceptions are the FBC 2001 relativities given for Terrain B in the High Velocity Hurricane Zone (i.e., Broward and Miami-Dade Counties). Buildings in the HVHZ must be designed for Terrain C, even if the actual terrain meets the requirements of Exposure Category B.

5.3.2 Secondary Factors for Group II Loss Relativities

Table 5-22 provides the secondary factors for parapets and inadequately restrained rooftop equipment for Group II buildings. Three sets of factors are provided: (1) parapets only, (2) rooftop equipment only, and (3) parapets combined with rooftop equipment. Tall parapets (minimum of 6 feet in height) reduce expected losses – particularly for building with metal roof decks, no secondary water resistance, and/or non-FBC equivalent roof coverings. The reduction in loss costs ranges from 24% for buildings with the weakest roofs to 2% for buildings with the strongest roofs. Unrestrained or poorly restrained rooftop equipment increases expected losses. The increase in loss costs ranges from 5% for buildings with the weakest roofs to 9% for buildings with the strongest roofs. The effect of parapets combined with rooftop equipment also varies depending on the types of roof construction and roof covering.

Table 5-22. Group II Secondary Factors for Parapets and Inadequately Restrained RoofTop Equipment

Roof Deck	*SWR*	*Roof Cover*	*Parapets*	*Unrestrained Rooftop Equipment*	*Both*
Metal	No	Non-FBC Equivalent	0.76	1.05	0.80
Metal	No	FBC Equivalent	0.88	1.06	0.94
Metal	Yes	Non-FBC Equivalent	0.92	1.07	0.99
Metal	Yes	FBC Equivalent	0.94	1.07	1.01
Concrete	N/A	Non-FBC Equivalent	0.95	1.09	1.03
Concrete	N/A	FBC Equivalent	0.98	1.09	1.06

In addition to the parapets and rooftop equipment secondary factor, the following Group I secondary factors from Table 5-11 also apply to Group II MF residential buildings:

- Opening coverage – all openings (Table 5-11, Item #4)

- Shutter interpolation between None and Hurricane (Table 5-11, Item #9)
- Wind, door, and skylight leakage potential (Table 5-11, Item #11)
- Roof Cover Age Interpolation (Table 5-11, Item #13)

The application of the secondary factors follows the methodology provided for SF homes in Section 4.2.5. First, the shutter interpolation factor should be applied to the primary relativity using Equation (4-2). Next, the FBC roof cover age interpolation factor should be applied (if applicable) using Equation (4-3). Any other secondary factors should then be combined using Equation (4-1b), and the final relativity should be computed using Equation (4-1a).

5.3.3 Discussion of Group II Loss Relativity Results

As expected, there is a wide range of relativities from the weakest to the strongest buildings. For Terrain B, the ratios of weakest to strongest relativities range between 5.4 in the lowest wind zone to 2.5 in the highest wind zone. For Terrain C, the ratios are larger, ranging from 8.3 in the lowest wind zone to 2.9 in the highest wind zone. The variation in the ratios is due to the fact that opening protection and FBC equivalent roof covers are much less likely to fail in the lower wind speed zones than in the higher wind speed zones. Nonetheless, the dollar savings in losses due to mitigation will be higher in the high wind speed zones because the frequency of severe events is higher and the expected losses for the base building class are higher.

5.4 Group III Buildings

Group III MF residential buildings are more than 60 feet in height. The typical roof deck types for Group III buildings are concrete or metal roof decks. The three construction eras modeled in the analysis of Group III buildings are:

1. 1982 or earlier, for which buildings designed to 1976 Standard Building Code (SBC 1976) are assumed to be typical.
2. 1983 through February 28, 2002, for which buildings designed to the 1988 edition of ASCE Standard 7 are assumed to be typical.
3. March 1, 2002 and later, for which buildings designed to the provisions of the 2001 Florida Building Code (FBC 2001) are assumed to be typical.

Both the building code era and visual inspection are required to determine the proper loss relativity.

5.4.1 Group III Loss Relativity Tables

The Group III loss relativity data for a 2% deductible (as a percentage of building replacement value) are given in Table 5-23 and Table 5-24 for Terrains B and C, respectively. To use these tables, one must obtain the following information:

1. ***The exposure category:*** Terrain B or Terrain C. Use the definitions given in Section A.1.1.1 of Appendix A. Note that the determination of the terrain type for the purposes of determining loss relativities for Group III buildings does not depend on whether the building is within the High Velocity Hurricane Zone (HVHZ).
2. ***The basic wind speed zone.*** Use the 2007 revision to FBC 2004 Figure 1609 or simply the county if the building is located in Broward, Miami-Dade, or Monroe County.
3. ***The design code era:*** SBC 1976, ASCE 1988, or FBC 2001. If the design code era is FBC 2001 and the building is located in the Wind Borne Debris Region (WBDR), then FBC 2001 design option is also required (Partially Enclosed or Enclosed). Note that the Partially Enclosed design option was removed from the FBC effective July 1, 2007.

Table 5-23. Group III Relativities for Terrain B

					Metal Roof Deck				Concrete	
					Non-FBC Equivalent Roof Covering		FBC Equivalent Roof Covering		Non-FBC Equiv. Roof Cover	FBC Equiv. Roof Cover
Actual Terrain	FBC Wind Speed	Model Design Code	FBC 2001 Design Option	Protection	No SWR	SWR	No SWR	SWR		
B	< = 100	SBC 1976 (Pre 1983)		None	**1.0000**	0.7429	0.7876	0.7091	0.4391	0.4135
				Hurricane	0.6324	0.3873	0.4283	0.3577	0.2644	0.2318
		ASCE 1988 (1983-2001)		None	0.9623	0.7906	0.8167	0.7681	0.6023	0.5806
				Hurricane	0.4491	0.3367	0.3465	0.3077	0.2761	0.2426
		FBC 2001 (2002-present)	Enclosed	None			0.3467	0.3070		0.1961
				Hurricane			0.2137	0.1940		0.1478
	101-110	SBC 1976 (Pre 1983)		None	**1.0000**	0.6863	0.7532	0.6521	0.4650	0.4322
				Hurricane	0.7716	0.4551	0.5199	0.4214	0.3497	0.3143
		ASCE 1988 (1983-2001)		None	0.8215	0.6065	0.6461	0.5760	0.5150	0.4847
				Hurricane	0.5238	0.3927	0.4087	0.3594	0.3541	0.3173
		FBC 2001 (2002-present)	Enclosed	None			0.4163	0.3520		0.2750
				Hurricane			0.3347	0.2896		0.2511
	111-120	SBC 1976 (Pre 1983)		None	**1.0000**	0.7315	0.8043	0.7081	0.4840	0.4611
				Hurricane	0.7434	0.4685	0.5431	0.4456	0.3497	0.3249
		ASCE 1988 (1983-2001)		None	0.8602	0.6630	0.7132	0.6413	0.5480	0.5272
				Hurricane	0.5261	0.4016	0.4313	0.3789	0.3549	0.3292
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.3821	0.3142		0.2905
				Hurricane			0.3601	0.3083		0.2806
	121-130	SBC 1976 (Pre 1983)		None	**1.0000**	0.7187	0.8095	0.6988	0.5183	0.4975
				Hurricane	0.8109	0.5265	0.6278	0.5089	0.4045	0.3834
		ASCE 1988 (1983-2001)		None	0.9294	0.7000	0.7877	0.6792	0.6187	0.5999
				Hurricane	0.6515	0.4928	0.5495	0.4747	0.4506	0.4345
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.4942	0.4088		0.3873
				Hurricane			0.4871	0.4155		0.3769
	131-140	SBC 1976 (Pre 1983)		None	0.7299	0.5270	0.5989	0.5141	0.4150	0.4014
				Hurricane	0.5869	0.4310	0.4898	0.4232	0.3534	0.3390
		ASCE 1988 (1983-2001)		None	**1.0000**	0.8221	0.8838	0.8143	0.6539	0.6370
				Hurricane	0.5899	0.4557	0.5047	0.4365	0.3695	0.3574
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.4265	0.3554		0.3428
				Hurricane			0.4248	0.3592		0.3308
	Broward	SBC 1976 (Pre 1983)		None	0.9010	0.6471	0.7531	0.6232	0.5272	0.5109
				Hurricane	0.7319	0.5503	0.6292	0.5322	0.4579	0.4379
		ASCE 1988 (1983-2001)		None	**1.0000**	0.7756	0.8680	0.7580	0.6697	0.6535
				Hurricane	0.6819	0.5220	0.5875	0.5078	0.4658	0.4530
		FBC 2001	Enclosed	Hurricane			0.5127	0.4374		0.4136
	Miami-Dade	SBC 1976 (Pre 1983)		None	0.8908	0.6462	0.7516	0.6243	0.5214	0.5063
				Hurricane	0.7196	0.5435	0.6230	0.5270	0.4470	0.4284
		ASCE 1988 (1983-2001)		None	**1.0000**	0.7854	0.8755	0.7687	0.6703	0.6556
				Hurricane	0.6738	0.5185	0.5847	0.5054	0.4565	0.4450
		FBC 2001	Enclosed	Hurricane			0.4919	0.4210		0.4104
	Monroe	SBC 1976 (Pre 1983)		None	0.8542	0.6446	0.7398	0.6262	0.4988	0.4868
				Hurricane	0.6732	0.5180	0.5937	0.5036	0.4020	0.3863
		ASCE 1988 (1983-2001)		None	**1.0000**	0.8207	0.8975	0.8061	0.6708	0.6580
				Hurricane	0.6448	0.5070	0.5721	0.4963	0.4209	0.4106
		FBC 2001 (2002-present)	Partially-Encl. Enclosed	None			0.5132	0.4179		0.3977
				Hurricane			0.4833	0.4085		0.3773

Table 5-24. Group III Relativities for Terrain C

					Metal Roof Deck				Concrete	
					Non-FBC Equivalent		FBC Equivalent		Non-FBC Equiv. Roof Cover	FBC Equiv. Roof Cover
Actual Terrain	FBC Wind Speed	Model Design Code	FBC 2001 Design Option	Protection	No SWR	SWR	No SWR	SWR		
C	< = 100	SBC 1976		None	**1.0000**	0.8127	0.8551	0.7906	0.4565	0.4361
		(Pre 1983)		Hurricane	0.4700	0.3436	0.3594	0.3155	0.2145	0.1888
		ASCE 1988		None	0.4137	0.2749	0.2947	0.2494	0.2479	0.2210
		(1983-2001)		Hurricane	0.3066	0.2123	0.2202	0.1879	0.2067	0.1800
		FBC 2001	Enclosed	None			0.2866	0.2461		0.1436
		(2002-present)		Hurricane			0.1862	0.1612		0.1140
	101-110	SBC 1976		None	**1.0000**	0.7564	0.8085	0.7244	0.4634	0.4372
		(Pre 1983)		Hurricane	0.5778	0.4179	0.4493	0.3863	0.3000	0.2683
		ASCE 1988		None	0.5043	0.3261	0.3596	0.2940	0.3158	0.2834
		(1983-2001)		Hurricane	0.4259	0.3018	0.3167	0.2696	0.2945	0.2627
		FBC 2001	Enclosed	None			0.3729	0.2981		0.2269
		(2002-present)		Hurricane			0.3078	0.2551		0.2092
	111-120	SBC 1976		None	**1.0000**	0.7934	0.8516	0.7716	0.4783	0.4610
		(Pre 1983)		Hurricane	0.5728	0.4269	0.4697	0.4053	0.2927	0.2712
		ASCE 1988		None	0.4877	0.3262	0.3719	0.3045	0.3113	0.2891
		(1983-2001)		Hurricane	0.4092	0.2936	0.3213	0.2716	0.2859	0.2640
		FBC 2001	Partially-Encl.	None			0.3058	0.2448		0.2318
		(2002-present)	Enclosed	Hurricane			0.3049	0.2496		0.2308
	121-130	SBC 1976		None	**1.0000**	0.7756	0.8601	0.7616	0.5092	0.4922
		(Pre 1983)		Hurricane	0.6708	0.5053	0.5695	0.4887	0.3561	0.3372
		ASCE 1988		None	0.6507	0.4429	0.5222	0.4271	0.4343	0.4147
		(1983-2001)		Hurricane	0.5520	0.4046	0.4600	0.3865	0.4002	0.3873
		FBC 2001	Partially-Encl.	None			0.4379	0.3517		0.3357
		(2002-present)	Enclosed	Hurricane			0.4270	0.3498		0.3359
	131-140	SBC 1976		None	**1.0000**	0.7294	0.8327	0.7093	0.5266	0.5107
		(Pre 1983)		Hurricane	0.7810	0.5620	0.6490	0.5458	0.4269	0.4054
		ASCE 1988		None	0.7816	0.5577	0.6468	0.5422	0.4987	0.4849
		(1983-2001)		Hurricane	0.6297	0.4447	0.5225	0.4234	0.4260	0.4054
		FBC 2001	Partially-Encl.	None			0.5205	0.4227		0.4228
		(2002-present)	Enclosed	Hurricane			0.5221	0.4215		0.3997
	Broward	SBC 1976		None	**1.0000**	0.7142	0.8378	0.6918	0.5413	0.5308
		(Pre 1983)		Hurricane	0.8163	0.5857	0.6924	0.5746	0.4608	0.4425
		ASCE 1988		None	0.7575	0.5271	0.6256	0.5140	0.5081	0.4900
		(1983-2001)		Hurricane	0.6306	0.4649	0.5367	0.4481	0.4569	0.4453
		FBC 2001	Enclosed	Hurricane			0.5358	0.4441		0.4231
	Miami-Dade	SBC 1976		None	**1.0000**	0.7218	0.8454	0.7014	0.5422	0.5328
		(Pre 1983)		Hurricane	0.8123	0.5867	0.6941	0.5766	0.4553	0.4382
		ASCE 1988		None	0.7581	0.5327	0.6320	0.5201	0.5086	0.4917
		(1983-2001)		Hurricane	0.6239	0.4610	0.5348	0.4450	0.4510	0.4400
		FBC 2001	Enclosed	Hurricane			0.5253	0.4276		0.4136
	Monroe	SBC 1976		None	**1.0000**	0.7511	0.8648	0.7329	0.5434	0.5337
		(Pre 1983)		Hurricane	0.7931	0.5856	0.6908	0.5743	0.4281	0.4118
		ASCE 1988		None	0.7655	0.5578	0.6555	0.5468	0.5110	0.4955
		(1983-2001)		Hurricane	0.5964	0.4416	0.5176	0.4273	0.4212	0.4099
		FBC 2001	Partially-Encl.	None			0.5542	0.4429		0.4260
		(2002-present)	Enclosed	Hurricane			0.5162	0.4263		0.4074

The data listed in Table 5-23 and Table 5-24 represent the relativities obtained at a representative location within each FBC basic wind speed zone. For each unique combination of terrain category and FBC basic wind speed zone, the loss costs have been normalized to an SBC 1976 with no opening protection, a non-FBC equivalent roof cover, no secondary water resistance, a non-concrete roof deck, no parapet, and no inadequately-restrained rooftop equipment present. For FBC wind zones of 131-140 and above in Terrain B, the loss costs are normalized to the ASCE 1988 buildings since they were designed to lower wind loads than the corresponding SBC 1976 buildings. The base building has been selected arbitrarily and the tables can be easily re-normalized by any other building type. A key point in the use of the tables is that they have been normalized within each terrain category and wind speed zone. The user determines the terrain category and wind speed zone using the one set of definitions, regardless of the year built.

As an example of how to use these tables, consider the case of a seven-story condominium building built in 1990 in Terrain B in Orlando. The building is reinforced concrete with a reinforced concrete roof deck and non-FBC equivalent roof cover. The building has no opening protection. Since the building was built in 1990, we use the ASCE 1988 relativities. The FBC design windspeed for Orlando is 110 mph. Therefore, we find the loss relativity to be 0.5150. This means that for 2% deductible (as a percentage of building replacement value) that the loss costs are 48% less than that of the reference SBC 1976 non-concrete deck building at that location.

Table 5-23 and Table 5-24 are based on minimal load designs for each building code era. Over design is not considered. The only exceptions are the FBC 2001 relativities given for Terrain B in the High Velocity Hurricane Zone (i.e., Broward and Miami-Dade Counties). Buildings in the HVHZ must be designed for Terrain C, even if the actual terrain meets the requirements of Exposure Category B.

5.4.2 Secondary Factors for Group III Loss Relativities

Table 5-25 provides the secondary factors for parapets and inadequately-restrained rooftop equipment for Group III buildings. As with the Group II buildings, three sets of factors are provided: (1) parapets only, (2) rooftop equipment only, and (3) parapets combined with rooftop equipment. Once again, parapets reduce the expected losses and unrestrained or poorly restrained rooftop equipment increases the expected losses. For Group III buildings, the reduction in loss costs due to parapets ranges from 19% for buildings with the weakest roofs to 3% for buildings with the strongest roofs. The increase in loss costs for unrestrained or poorly restrained rooftop equipment ranges from 5% for buildings with the weakest roofs to 7% for buildings with the strongest roofs. The effect of parapets combined with rooftop equipment also varies depending on the types of roof construction and roof covering.

Table 5-25. Group III Secondary Factors for Parapets and Inadequately-Restrained Rooftop Equipment

Roof Deck	*SWR*	*Roof Cover*	*Parapets*	*Rooftop Equipment*	*Both*
Metal	No	Non-FBC Equivalent	0.81	1.05	0.85
Metal	No	FBC Equivalent	0.89	1.05	0.94
Metal	Yes	Non-FBC Equivalent	0.91	1.06	0.97
Metal	Yes	FBC Equivalent	0.94	1.06	1.00
Concrete	N/A	Non-FBC Equivalent	0.93	1.07	1.00
Concrete	N/A	FBC Equivalent	0.97	1.07	1.04

In addition to the parapets and rooftop equipment secondary factor, the following Group I secondary factors from Table 5-11 also apply to Group III MF residential buildings:

- Opening coverage – all openings (Table 5-11, Item #4)
- Shutter interpolation between None and Hurricane (Table 5-11, Item #9)
- Wind, door, and skylight leakage potential (Table 5-11, Item #11)
- Roof Cover Age Interpolation (Table 5-11, Item #13)

The application of the secondary factors follows the methodology provided for SF homes in Section 4.2.5. First, the shutter interpolation factor should be applied to the primary relativity using Equation (4-2). Next, the FBC roof cover age interpolation factor should be applied (if applicable) using Equation (4-3). Any other secondary factors should then be combined using Equation (4-1b)(4-1b), and the final relativity should be computed using Equation (4-1a) (4-1a).

5.4.3 Discussion of Group III Loss Relativity Results

As with the Group II relativities, there is a wide range of relativities from the weakest to the strongest buildings. For Terrain B, the ratios of weakest to strongest relativities range between 6.8 in the lowest wind zone to 2.7 in the highest wind zone. For Terrain C, the ratios are larger, ranging from 8.8 in the lowest wind zone to 2.5 in the highest wind zone. Again, the variation in the ratios is due to the fact that opening protection and FBC equivalent roof covers are much less likely to fail in the lower wind speed zones than in the higher wind speed zones. Nonetheless, the dollar savings in losses due to mitigation will be higher in the high wind speed zones because the frequency of severe events is higher and the expected losses for the base building class are higher.

6 Implementation

6.1 Introduction

Sections 4 and 5 developed the loss relativity tables and secondary factor tables for single family and multi-family residences, respectively. This section provides step-by-step procedures that summarize the computation of loss relativities for a residential building. In addition, the steps to convert a relativity into an insurance credit or rate differential are also included.

Section 6.2 discusses the needed elements of a wind loss mitigation program and insurance rate differential implementation. Section 6.3 reviews the conversion of loss relativities into insurance rate differentials. Sections 6.4 and 6.5 provide the step-by-step procedures for determining rate differentials for single family and multi-family residences, respectively.

6.2 Implementation Concepts and Discussion

There are several possible long-term measures of implementation success in terms of wind loss mitigation and insurance rate differentials. First, Florida's vulnerability to hurricane damage should reduce over time as more buildings are mitigated. As new FBC structures are added to the statewide building stock each year, insured losses (as a percentage of the inflation-adjusted total building inventory exposure in the state) will reduce over time. Second, if pre-FBC building owners invest in mitigation, additional reductions in loss are achievable. Third, insurance capacity and availability should improve over the long-term with a significantly improved statewide building stock and demonstrated loss reduction.

Wind mitigation rate differentials should be implemented as part of a multi-faceted program that:

1. Requires accurate determination the presence/absence of wind mitigation features.
2. Encourages building owners to invest in cost-effective mitigation to achieve lower insurance rates.
3. Encourages insurance companies to collect wind mitigation data on their portfolio of buildings so that rates can be accurately determined.
4. Provides for adequate and fair rates for insurance companies. The implementation of rate differentials should be a "win-win" situation for the insurance company and the building owner.
5. Encourages reinsurance programs to reflect the actual distribution of wind mitigation features within an insurance company portfolio.
6. Promotes continued improvements to the Florida Building Code.
7. Promotes validation, updates, and refinements to loss mitigation modeling, building ratings, and rate differentials.

A program that neglects one or more of these facets will underperform. Florida's insurance implementation of its wind mitigation program needs significant improvement. Maximum long-term success will occur when an insurance company inspects its book of business in the high wind zones, provides each building owner with a mitigation report that includes rate differential information (economic incentives) for improvements to the building, and applies the loss relativities as rate differentials. Applying the loss relativities as rate differentials avoids the problems associated with a credit program that is based on normalization of relativities to the weakest structure.

The following paragraphs discuss additional concepts with respect to implementation.

Maintain All Mitigation Features in the Implementation. The loss relativity tables in this report are more numerous and larger than those in the 2002 studies. One implementation question regards

possible simplification of these tables and equations for insurance company application. Since each building is a system in which weakness in a single component can dramatically affect the performance of the system, all of the identified mitigation features and techniques should be maintained in the final implementation. As illustrated in Section 4, we recommend that the complete loss relativity tables and all secondary factors be considered in the final implementation. We do not believe that simplification of the tables or eliminating some of the secondary factors is in the best long-term interest of the state. For example, each 1% in loss reduction that is achieved on a statewide basis reduces the average annual hurricane losses in Florida by about 50 million dollars. Therefore, ignoring or not promoting techniques or fixtures that may have small loss reduction effects would result in missed loss reduction opportunities. These missed opportunities can aggregate into billions of dollars over time. Further, we believe there is little administrative benefit in simplification since the loss relativity tables are very small when compared to typical insurance company data sets and the calculation approach is easily programmable. Finally, the inspection information required for additional loss mitigation features is either already obtained on the current inspection form or can be readily added to the inspection process.

Consider Incentives for Insurance Companies. Implementation of the loss relativities should be done in a way that clearly promotes investment in mitigation. We do not think implementation has been very successful in Florida, since it is viewed as an "insurance credit program" and the emphasis has been on getting "credits" vs. cost-effective mitigation with the mitigation costs largely offset by reduced insurance premiums over time. The program needs to evolve to one where building owners realize that investing in certain cost-effective mitigation steps for their building is a form of savings that provides a return on investment. Once a pre-FBC building is inspected, the building owner should receive a clear report that shows the building's mitigation features, what rate differentials it qualifies for, and how further rate reductions can be achieved with specific cost-effective mitigation improvements.

The fundamental way to measure the success of the program is to quantify loss reduction through building owner investment in mitigation. Establishing a performance-based incentive for insurance companies might help.[36] Investing in mitigation should produce a win-win situation for the building owner and the insurer. Real incentives for insurance companies to promote mitigation could help the long-term success of the program.

Promote Mitigation Economics. The economic engine of rate differentials needs to be promoted through many communication avenues. New structures built to improved standards have lower lifetime costs, when one considers the initial incremental (mitigation) construction cost, the life of the structure, and the reduced average annual losses from hurricanes. Existing structures that are vulnerable to hurricane damage can generally be mitigated to some significant degree such that the initial cost of mitigation is offset by reduced average annual losses and reduced insurance costs. In summary, proper implementation of wind mitigation rate differentials should encourage (1) continual improvements to building code standards, and (2) owner investments in wind mitigation to achieve the resulting benefits of reduced insurance premiums.

Inspections are a Cornerstone of Success. The application of the loss relativities involves the determination of insurance rate differentials. This determination requires knowledge of how base rates match up with relativities and the need to determine what wind mitigation features are on a building. How the base rates are mapped into the relativity tables determines how the rate differentials are turned into credits and/or surcharges. Numerous approaches are feasible. An accurate and reliable determination of what the rate differential should be generally requires a competent inspection of the building for pre-FBC construction. Within an insurance company's book of business, there are buildings that have been inspected for wind mitigation features, have not been inspected, or have some features that have been self-determined (partial inspection). This situation produces what might be called different "classes" within a line of business. Each class may have some average wind mitigation loss relativity; however,

[36] For example, a rate-of-return incentive based on a company's success in getting its pre-FBC customers to invest in mitigation.

only the inspected class will have a pre-determined average class relativity. A statistical sample of inspections may be needed for some classes to determine how to quantify the base rate changes between classes.

Building Code Evolution. An inherent complication in the implementation of wind mitigation rate differentials is that building codes change over time and our knowledge and quantification of loss reduction change over time. Hence, as the loss relativities are updated periodically, the magnitudes of the relativities change for individual buildings and this affects the rate differentials. Getting this point across to the public may be challenging, particularly for those whose rate differential amount changes notably. For example, two story homes and tile roof covers are considered in this study but were not considered in the 2002 study. Also, and as noted in previous sections, the overall magnitudes of the relativities for well-built buildings are similar to the 2002 study when the 2008 tables are normalized to the same reference building in the 2002 study. For weaker buildings, since more features are included in this study, the tables have a wider range of relativity than in 2002. In summary, one implementation consideration is whether to gradually implement the new rate differentials for buildings that received a credit previously, particularly for those with a rate differential "shock". Clearly, for buildings that have not been receiving a rate differential, there is no previous history and no implementation issue.

6.3 Transforming Loss Mitigation Relativities into Insurance Rate Differentials

Loss relativities quantify loss cost differences for buildings with different mitigation features. Hence, they can be used to determine insurance rate differentials. As previously noted, there are several key qualifications in the application of the loss relativity tables for rate differentials:

1. The rate differentials apply only to the portion of the wind premium loss costs that covers the dwelling, contents, and loss of use. The loss relativities do not apply to that portion of the wind premium that covers attached or detached structures, even those that may be included under Coverage A. Hence, insurance companies must determine how to allocate wind premium among dwelling-related losses and attached and detached structure-related losses. The loss relativities developed herein also assume that losses from attached/detached structures do not accrue to the 2% dwelling deductible.
2. The loss relativity rate differentials have been developed only for buildings that meet minimal standards of condition. These include:
    a. Roof Cover
    b. Openings
    c. Roof Deck

    Roof cover and openings (windows, doors, skylights, etc) must be in reasonably good and repairable condition. If these components are in a state of notable disrepair, the building should not qualify for rate differentials until the components are put into good condition. This qualification applies particularly to roof covers, which are a significant component of wind-related loss costs. Single-family residences and Group I multi-family residences must also have at least a roof deck strength that is Type A or better to qualify for wind mitigation rate differentials.
3. The rate differentials developed in this report are strictly applicable only to 2% deductible cases and the insurance parameters discussed in Section 2.7.

The following paragraphs summarize some basic concepts regarding the conversion of wind loss relativities into rate differentials or credits.

Rate Differentials. The rate differentials for 2% deductible can be seen directly from the loss relativity tables.[37] For example, in Table 4-5, the rate of the weakest house should be 3.2352 times the rate of the typical house; similarly the rate of the strongest house in Table 4-6 should be 0.4287 times the rate of the typical house. These same rate differentials can be developed from the information in Table 4-9 and Table 4-10 for Terrain B. For example, the weakest house rate is 1.000/0.3091 = 3.2352 times the typical house rate.

Credits From the Weakest Building. This format is the rate differential approach adopted by the Florida OIR following the 2002 studies. Credits from the weakest building can be directly computed easily from the loss relativity tables according to the formula:

$$C = 1 - r/r_{weakest} \qquad \textbf{(6-1)}$$

where C = credit fraction applied to a base rate for a territory and line of business and r = loss relativity normalized to any house. For tables that have already been normalized by the relativity of the weakest building (for example, see Table 4-9 through Table 4-12), Equation (6-1) reduces to:

$$C = 1 - R \qquad \textbf{(6-2)}$$

where $R = r/r_{weakest}$.

Credits are subtracted from the rate to achieve the rate differential. For example, if the applicable wind premium rate for the weakest building is $1000, the credit for the weakest building is 1 - 1 = 0, which means the rate for the weakest house is $1000 – 0 = $1000. Similarly, for a typical Terrain B building discussed above, the credit is computed by C = 1- 0.3091 = 0.6909. This fraction is used to determine a credit of 0.6909*$1000 = $690.90, which means the premium for this building is $309.10. Obviously, the loss relativity rate differential of 0.3091 is preserved for a credit implementation approach, where credits are all computed from the weakest building.

The problem with applying credits from the weakest building is that the base rate should be based on the loss costs of the weakest building. The loss costs of the weakest building can only be developed through a model, similar to the process used herein. Generally, base rates are more reflective of the expected loss costs, statistically averaged over strong and weak buildings, which is significantly different than the loss costs of the weakest structure. If the credits are computed from the weakest building but are applied using rates that are derived from an average building, then there is a significant economic disconnect. This disconnect can be alleviated with a proper rate effect or offset calculation that reflects the rate differentials and an insurer's distribution of business.

A final point on rate differentials and credits regards the fact that the range (weakest relativity divided by strongest relativity) will increase with increasing knowledge regarding what features are significant in determining rate differentials. As more knowledge is gained on the wind performance of buildings, the ability to estimate differences for mitigation features increases and hence the relative differences become larger. For example, in this study, we see that the weakest single-family house in Terrain B has a relativity of 3.23, which is greater than the weakest building in the 2002 study, which had a relativity of 2.37.[38] Hence, one would expect that rate differentials to become broader as more mitigation features are considered and quantified.

[37] Our use of the term rate differential in this report refers only to the rate associated with the portion of the wind premium that applies to the dwelling, contents, and loss of use coverage. The rate differential should not be applied to any portion of the wind premium associated with attached or detached structures.

[38] The single family and Group I "typical" buildings are the same for the 2002 study and this study.

Rate Effect or Offset. Rate effect or offset calculations can be used with the loss relativity tables to determine what the rate differentials should be for a given book of business.[39]

Knowledge of the book of business provides estimates of the frequencies of buildings in each cell in the loss relativity tables. These frequencies can be estimated sufficiently accurately with a random sample of inspections coupled with other more generally-known information such as year built, number of stories, and roof cover type, etc.

If an insurance company decides to inspect its book of business (over several years, if needed), the distribution of business becomes known and the resulting rate effect calculation provides the best technical way to adjust the base rate. This adjustment can be done annually as new business enters the book and is inspected, resulting in a distribution of business that remains accurate. In this approach, the loss relativities are implemented as rate differentials for the entire population of business. This approach is stable and the rate differentials are systematically reflected across the book.

Few, if any, insurers have inspected their entire book. In general, insurers have two subpopulations in their single-family residential book. One subpopulation consists of homes that have had mitigation "inspections" (or are post-FBC homes) and are receiving credits. Another subpopulation consists of houses that have not been inspected and either are not receiving credits, or are receiving partial credits for a few features for which the insurance company has data. The challenge in this case is to determine what the distribution of business is in the "non-inspected" populations. A statistical sampling procedure could be used to design an inspection survey and develop the necessary data to determine what the base rate difference should be between the two subpopulations within the book. That is, the rate effect on the inspected population is easily determinable from the inspection data. A rate effect on the non-inspected population is estimated by a sample of inspections. The appropriate and fair base rate will be applied to both classes. For example, if the inspected class has an average relativity that is ½ of the non-inspected class average relativity, the rate differentials for the inspected class could be computed using ½ the base rate of the non-inspected class. That is, based on the inspection data, the inspected class would be expected on average to have ½ the loss costs of the non-inspected class and the base rates for the two classes would properly reflect the book of business. This approach can also be robust provided the average relativity of the non-inspected class is kept up to date. As more post-FBC buildings enter the book, the average relativity of the inspected class reduces and the base rate differential of the two populations would be expected to increase over time.

Impact of Attached and Detached Structures. Attached and detached structures generally are much more vulnerable to losses than the dwelling structure. The reader is urged to review the OIR report by Twisdale, Sciaudone, Vickery, Chen, and Wadhera (2007). If insurers apply the rate differentials developed herein to the total wind premium, they will not collect adequate premium to cover the losses associated with attached and detached structures. These structures have higher loss costs than the dwelling since they are not built to the same building code requirements and level of quality as the dwelling. Loss data confirms that the loss fractions for these structures are higher than those of the dwelling

We performed some simulations to gauge how important it is to exclude attached and detached structures from the wind mitigation rate differentials. We simulated a house in which 10% of Coverage A reflected the presence of an attached aluminum frame screen enclosure. We used a windspeed loss function for the screen enclosure developed from load and resistance modeling, validated against damage survey data. Screen enclosures are more vulnerable that the dwelling and they often fail catastrophically,

[39] Book of business refers to knowledge of the statistical frequency distribution of mitigation features for the buildings in that book. The frequency distribution assigns probabilities to each cell in the loss relativity table. Section 5 in the 2002 loss relativity study discusses this issue. New work on distribution of business has not been undertaken in this study since each insurer's distribution is likely to be notably different from generic distributions.

requiring total replacement. When we included the screen enclosure in the loss relativity analysis, the range of loss relativities was reduced about 40%. This means that the relativity of the strongest house (with a weak screen enclosure) almost doubled over the case of a strong house with no screen enclosure. Hence, the 'credit' would be almost ½ that of the same house with no screen enclosure.

This example illustrates the impact of dwelling-independent losses arising from weak attached or detached structures on loss relativities. Obviously, these results depend on the value of the enclosure compared to the value of the house and the location within Florida. Clearly, the loss relativities developed in Section 4 would be more compressed, and the magnitude of the relativity credits would be smaller if attached and detached structures had been included in the analysis. Hence, insurers definitely should exclude that portion of the wind premium that is associated with attached and detached structures in any rate differential implementation.

6.4 Rate Differential Steps for Single Family and Group I Multi-family Residences

Loss relativity implementation steps and examples are presented in this section for single family residences. The approach for Group I residences is identical to single family houses with the exception that Group I multi-family residences do not include reinforced concrete roof decks. Group I buildings with reinforced concrete roof decks are evaluated as Group II buildings. Group I buildings with a flat roof also have a parapet and rooftop equipment factor.

6.4.1 Implementation Steps.

Table 6-1 summarizes which secondary factors are applicable to single family and Group I residences. This table is based on the discussion in Section 4.

Table 6-1. Implementation of Secondary Factors for Single Family and Group I Residences.

Secondary Factors (from Table 4-15)		Pre-FBC		2001-FBC		2006-FBC	
		Other Roof Deck	Reinforced Concrete Roof Deck	Other Roof Deck	Reinforced Concrete Roof Deck	Other Roof Deck	Reinforced Concrete Roof Deck
1	Dimensional Lumber Deck[1]		NA		NA		NA
2	Unreinforced Masonry Walls[2]		NA	NA	NA	NA	NA
3	Reinforced Masonry Walls[2]		NA		NA		NA
4	Opening Coverage - All Openings[3]						
5	Unbraced Gable End		NA	NA	NA	NA	NA
6	Foundation Restraint		NA	NA	NA	NA	NA
7	Reinf. Concrete Roof Deck (Table 4-16)	NA		NA		NA	
8	Enhanced Roof Deck[1]		NA		NA		NA
9	Shutter Interpolation[4]						
10	Vinyl Siding						
11	Window / Door Leak Potential						
12	Double Wrap Roof-to-Wall Connection		NA	NA	NA	NA	NA
13	Roof Cover Age Interpolation						
14	Partially Enclosed Design (FBC 2001)	NA	NA			NA	NA

[1] Secondary Factors 1 and 8 are mutually exclusive.

[2] Secondary Factors 2 and 3 are mutually exclusive.

[3] Applies only to hurricane level of protection; not applicable in post FBC in HVHZ except for Reinforced concrete roof deck Table 4-16. For post-FBC HVHZ other roof deck, tables already include all openings protected.

[4] NA to HVHZ since wood panel shutters are not acceptable in HVHZ

Following are a sequence of steps for implementation of the 2008 single family residential loss relativities. The Group I buildings follows the same sequence of steps. These steps are presented as the technical approach for determining the loss relativity for a building. However, the steps for computing credits and rate differentials are illustrative and do not necessarily constitute a final "OIR-approved" approach for determining credits or rate differentials.

1 ***Step I. Pre or Post-FBC:*** Determine if the residence is pre-FBC or post-FBC.

2 ***Step II. Pre-FBC Relativity:*** For pre-FBC residences, use the following steps:

a. Step A. Determine Base Relativity (R).

If roof deck is reinforced concrete integrally tied to reinforced concrete or reinforced masonry walls, use Table 4-16 to determine R.

i. If roof deck is not reinforced concrete, determine the appropriate cell for the residence from Table 4-9 and Table 4-10 for Terrain B locations and Table 4-11 and Table 4-12 for Terrain C locations.

b. Step B. Opening Protection Interpolation and Roof Cover Age Interpolation (if needed).

i. Opening Protection Interpolation (apply before roof cover age interpolation).

1. If opening protection is none or hurricane, no interpolation is needed.
2. If opening protection qualifies as Ordinary, OSB, Plywood, or Basic, use interpolation to compute R. Apply Equation (4-2) with the shutter interpolation factors (Factor 9) given in Table 4-15.

ii. Roof Cover Age Interpolation

1. If an FBC roof cover is less than or equal to 5 years old, use the relativity from the FBC portion of the table and no interpolation is needed.
2. If an FBC roof cover is tile, cement, slate or metal and is 20 years or older, or if it is any other material and 15 years or older use the non-FBC roof cover relativity and no interpolation is needed.
3. For FBC roof cover ages between these limits, interpolate the relativity using Equation (4-3) with the A values from Table 4-15.
4. Note that if opening protection interpolation is needed, then the FBC interpolation will require the interpolation of opening protection (first) for both FBC and non-FBC roof covers.

c. Step C. Apply Other Secondary Factors (Ki) to Produce Updated Relativity (R').

i. If the residence does not have a reinforced concrete roof deck, apply the secondary factors from Table 4-15 for the following features:

1. Dimensional Lumber Deck
2. Unreinforced Masonry Walls
3. Reinforced Masonry Walls (mutually exclusive with No. 2)
4. Opening Coverage-All Openings
5. Unbraced Gable End
6. Foundation Restraint
7. NA
8. Enhanced Roof Deck (mutually exclusive with No. 1)
9. Computed in Step II B, if needed
10. Vinyl Siding
11. Window/ Door Leak Potential
12. Double Wrap Roof-to-Wall Connection
13. Computed in Step II B, if needed

14. NA to pre-FBC construction
15. Parapets and RTE (applies only to Group I buildings with flat roofs)

ii. If the residence has a reinforced concrete roof deck, apply the following secondary factors, if applicable:

1. Opening Coverage-All Openings (Hurricane Protection only)
2. Vinyl Siding
3. Window/ Door Leak Potential

iii. Compute aggregate *K* factor from Equation (4-1b).

iv. Compute updated relativity (*R'*) from *K* using Equation (4-1a).

3 ***Step III. Post-FBC Relativity:*** For post-FBC residences, use the following steps:

a. Step A. Determine the Base Relativity R.

i. If roof deck is reinforced concrete integrally tied to reinforced concrete or reinforced masonry walls, use Table 4-16 to determine R for all post-FBC construction.

ii. If the roof deck is not reinforced concrete, determine the applicable FBC code (2001 or 2006).

1. If the applicable FBC code is 2006, use Table 4-17 for Terrain B and Table 4-18 for Terrain C.

2. If the applicable FBC code is 2001, use Table 4-21 for Terrain B and Table 4-22 for Terrain C.

b. Step B. SWR, Opening Protection Interpolation, and Roof Cover Age Interpolation.

i. Secondary Water Resistance

1. If the residence has secondary water resistance, apply the appropriate SWR factor from Table 4-19 or Table 4-20 for FBC 2006 and from Table 4-23 or Table 4-24 for FBC 2001.
2. The SWR factor is applied first to post-FBC relativities before opening protection and/or roof cover age, if needed.

ii. Opening Protection Interpolation.

1. If opening protection is none or hurricane, no interpolation is needed.
2. If opening protection qualifies as Ordinary, OSB, Plywood, or Basic, use interpolation to compute R. Apply Equation (4-2) with the shutter interpolation factors (Factor 9) given in Table 4-15.

ii. FBC Roof Cover Age Interpolation

1. If an FBC roof cover is less than or equal to 5 years old, use the relativity from the FBC portion of the table and no interpolation is needed.
2. If an FBC roof cover is tile, cement, slate or metal and is 20 years or older, or if it is any other material and 15 years or older use the non-FBC roof cover relativity and no interpolation is needed.
3. For FBC roof cover ages between these limits, interpolate the relativity using Equation (4-3) with the A values from Table 4-15.

4. Note that if opening protection interpolation is needed, then the FBC interpolation will require the interpolation of opening protection (first) for both FBC and non-FBC roof covers.

c. Step C. Apply Other Secondary Factors (Ki) to Produce Updated Relativity (R').

i. If the residence has a reinforced concrete roof deck, apply the following secondary factors from Table 4-15, if applicable:
   1. Opening Coverage-All Openings (non HVHZ locations only)
   2. Vinyl Siding
   3. Window/ Door Leak Potential
   4. Partially Enclosed Designs

ii. If the residence does not has a reinforced concrete roof deck, apply the secondary factors from Table 4-15, if applicable:
   1. Dimensional Lumber Deck
   2. Reinforced or Unreinforced Masonry Walls
   3. Opening Coverage-All Openings (non HVHZ locations only)
   4. Enhanced Roof Deck (mutually exclusive with No.1)
   5. Vinyl Siding
   6. Window/ Door Leak Potential
   7. Partially-Enclosed Design

iii. Compute aggregate *K* factor from Equation (4-1b).

iv. Compute updated relativity (*R'*) from *K* using Equation (4-1a).

4 Step IV. Compute Rate Differential (D) or Credit (C):

a. For a rate differential applied to a rating class, here is one approach to determining the rate differential:

i. Compute the average (expected value) loss relativity ($E(R')$) of all the buildings in the rate class. This requires knowledge of the statistical distribution of business with respect to mitigation features.

ii. Determine how the base rate (less attached and detached structures) for the rating class relates to the average relativity. Call the applicable base rate B.

iii. Compute the rate for the building in question according to:

$$Rate = B*R'/E(R') \qquad \textbf{(6-3)}$$

iv. The rate differential fraction from the average relativity (building) is

$$D = E(R') - R', \qquad \textbf{(6-4)}$$

where the difference can be positive or negative. Positive differences mean the rate is less than average for this class and negative differences mean the rate is more than average for this class. The rate differential from the weakest to the strongest building is $D = 1 - R'$.

v. Ensure consistency between rate class base rates (such as an inspected rate class and an uninspected rate class) by determining the average (expected value) relativity for each class.

b. For the case of credits (*C*) computed without adjustment for average relativity within a rate class:

i. Determine if credits will be from the weakest building or some other reference building.

1. If the credits are computed from the weakest building, the credit fraction off of the weakest building is simply $C = 1 - R'$
2. If credits are computed from some other reference building:

a. Select the reference building (cell) from the appropriate relativity table which has been normalized to the weakest building.
b. Compute a new reference relativity (R") according to $R''=R'/R_{ref}$ where R_{ref} is the relativity of the reference building.
c. Determine how to treat $R'' > 1$. For example, no credits apply or surcharges apply for all $R'' >1$.
d. Compute the credit from $C= 1-R''$, where positive C = credit, and negative C = no credit or a surcharge.

c. For some hybrid case of credits that require some some minimal strength (minimum R required), use a combination of the rate differential and credit approaches outlined above.

d. Note that D or C applies to only that portion of the wind premium that pertains to the dwelling structure, its contents, and additional living expenses.

i. D or C do not apply to attached or detached structures that are not under the main roofing system of the dwelling, such as screen enclosures, fences, storage sheds, detached garages, gazebos, swimming pools, carports, etc. These other structures are not built to the same building code standards as the dwelling and generally have loss costs that are higher than those of the dwelling.

ii. The insurance company must therefore determine what portion of the wind premium to which D or C should be applied. This is a significant and important step in the proper application of wind mitigation rate differentials.

iii. The loss relativity tables herein have been determined for a single deductible and a single set of coverage ratios. Loss relativities depend on the deductible (see 2002 study). The determination of how relativities vary with deductible and coverage ratio should be considered by the insurance company, particularly if the deductibles and coverage ratios are different than those analyzed in this study.

6.4.2 Example Calculations of Credits and Rate Differentials

1. ***Pre-FBC Residences.*** We illustrate the calculation of rate differentials using the above steps for several cases.

a. ***Credit from Weakest House-Case A.*** Terrain B Residence with: roof slope = 7:12; two-story, tile, hip; no SWR: non–FBC roof cover; 8d deck nails at 12 inch spacing (Type B); clip roof to wall connection; no shutters; wood soffits. House has 16 double hung windows, 2 sliding glass doors, and 2 entry doors, with no skylights.

i. ***Step II A.*** The base relativity is looked up in Table 4-9 and R = 0.4532.
ii. ***Step II B.*** No interpolation is needed since house does not have shutters.
iii. ***Step II C.*** The only secondary factor that applies is No. 11 (Window/ Door Leak Potential). We perform the following calculation using the information in Table 4-15.

1. The total count for openings is 16 + 2 * 4 + 2 = 26, where each slider counts as 4 openings.
2. The K_i factor for all window types except casement and fixed for 21 to 30 openings is 1.11 for a house with no shutters.
3. We compute R' using Equation (4-1a) according to $R' = 0.4532*1.11^{(1-0.4532)} = 0.4798$.

iv. ***Step IV b.*** The credit from the weakest house is simply C = 1- 0.4798 = 0.5202 or 52.0%.

b. ***Credit from Weakest House-Case B.*** Terrain B Residence with: roof slope = 4:12; one-story, shingle, gable; no SWR: 4-year old FBC roof cover; 8d deck nails at 6 inch spacing (Type C); wrap roof-to-wall connection; plywood shutters over windows only; enhanced roof deck; vinyl siding; and wood soffits. House has 10 casement windows, 1 sliding glass doors, and 2 entry doors, with no skylights.

i. ***Step II A.*** Since this house has opening protection between none and hurricane, we need to look up two base relativities. The base relativities are looked up in Table 4-9 and R_N = 0.1745 and R_H = 0.1575.

ii. ***Step II B.*** The shutter interpolation follows from Equation (4-2). From Table 4-15, we see that the interpolation factor is S = 0.48. Hence, the interpolated relativity is R = 0.1575+ (0.1745 -0.1575)*0.48 = 0.1657.

iii. Step II C.

1. The K_i values from Table 4-15 are 0.96 and 1.02, respectively, for enhanced roof deck and vinyl siding.
2. For window/door leak potential, the total count for casement/fixed openings is 10 and K_i = 1.01 for non-porous shutters.
    a. For the 1 slider and 2 entry doors, we use the "other" window type in Table 4-15. We compute 1 * 4 + 2 = 6 where each slider counts as 4 openings. For 1 to 10 "other" openings, K_i = 1.02 for non-porous shutters.
    b. The combined K for leakiness is 1.02 * 1.01 = 1.03.
3. The aggregate K is given by Equation (4-1b), where K = 0.96 * 1.02 * 1.03= 1.009.
4. We compute R' using Equation (4-1a) according to $R' = 0.1657 * 1.009^{(1-0.1657)} = 0.1669$.

iv. ***Step IV b.*** The credit from the weakest house is simply C = 1 - 0.1669 = 0.8331 or 83.3%.

c. Rate Differential: Cases A and B.

i. Assume that the average relativity has been estimated for a rating class, for example $E(R)$ = 0.4166 for Terrain B locations.
ii. Assume that the average Base Rate is $5.00 per thousand.
iii. The rate for the Case A Residence = 0.4798/0.4166 * $5.00 = $5.759.
iv. The rate for the Case B Residence = 0.1669/0.4166 * $5.00 = $2.003.

2. ***Post-FBC Residences.*** For post-FBC residences, we develop three examples.

a. ***Credit from Weakest House: 2006 FBC Construction.*** House is 2 story shingle, gable roof with 8:12 roof slope located in Terrain C in a 110 mph design windspeed location. House has no opening protection with 20 jalousie windows, no sliding glass doors, 10 casement windows, and 3 entry doors, with one skylight.

i. ***Step III A.*** The base relativity is looked up in Table 4-18 and R_{FBC} = 0.2597.
ii. ***Step III B.*** No interpolation is needed for opening protection or FBC roof cover.

iii. ***Step III C.*** The only secondary factor that applies is No. 11 (Window/ Door Leak Potential). We perform the following calculation using the information in Table 4-15.
    1. The total count for openings is 20 + 3 + 1 = 24, all treated as "other" openings.
    2. The K_i factor for all window types except casement and fixed for 21 to 30 openings is 1.11 for a house with no shutters.
    3. The K_i factor for 10 casement windows is 1.03.
    4. The total $K = 1.11 \times 1.03 = 1.14$.
    5. We compute R' using Equation (4-1a) according to $R' = 0.2597*1.14^{(1-0.2597)} = 0.2862$.

iv. ***Step IV b.*** The credit from the weakest house is simply $C = 1- 0.2862= 0.7138$ or 71.4%.

b. ***Credit from Weakest House: 2001 FBC Construction.*** House is 1 story with tile roof cover, wood soffits, hip roof shape with 5:12 slope and is located in Terrain C in HVHZ with non-porous shutters. House has 13 casement windows, 2 fixed glass windows, and 4 entry doors. Roof cover is 6 years old.
    i. ***Step III A.*** The base relativity is looked up in Table 4-22 and $R = 0.1405$.
    ii. ***Step III B.*** No interpolation is needed for opening protection, but is needed for FBC roof cover age.
        1. Determine Δ from the Non-FBC part of Table 4-22, where $R_{non\text{-}FBC} = 0.2261$. Hence, from Equation (4-3a), $\Delta = 0.0856$.
        2. Use Equation (4-3b) to compute $R = 0.1405 + 0.0856*(6-5)/(20-5) = 0.1462$.
    iii. ***Step III C.*** The only secondary factor that applies is No. 11 (Window/ Door Leak Potential). We perform the following calculation using the information in Table 4-15.
        1. The total count for casement/fixed openings is 13 + 2 = 15.
        2. The K_i factor for casement and fixed windows with 11 to 20 openings is 1.03 for a house with non-porous shutters.
        3. The K_i for 4 entry doors protected by non-porous shutters is 1.02.
        4. The combined K for window/door leaks is 1.03 * 1.02 = 1.05
        5. We compute R' using Equation (4-1a) according to $R' = 0.1462*1.05^{(1-0.1462)} = 0.1524$.
    iv. ***Step IV b.*** The credit from the weakest house is simply $C = 1 - 0.1524 = 0.8476$ or 84.8%.

c. ***Rate Differential: FBC Cases A and B.***
    i. Assume that the average relativity has been estimated for different rating classes, for example $E(R) = 0.4500$ for 110 mph Terrain C and $E(R) = 0.3232$ for HVHZ Terrain C locations.
    ii. Assume that the average Base Rate is $3.00 per thousand for 110 mph Terrain C in this territory and $8.00 for HVHZ Terrain C..
    iii. The rate for the 2006 FBC residence = 0.2862/0.4500*$3.00 =$1.908.
    iv. The rate for the 2001 FBC residence = 0.1524/0.3232*$8.00 =$3.772.

6.5 Rate Differential Steps for Group II and Group III Multi-Family Residences

Loss relativity implementation steps and examples are presented in this section for Group II MF residential buildings. The approach for Group III buildings is identical to Group II.

6.5.1 Implementation Steps

Following are a sequence of steps for implementation of the 2008 Group II and Group III multi-family loss relativities. These steps are presented as the technical approach for determining the loss relativity for a building. However, the steps for computing credits and rate differentials are illustrative and do not necessarily constitute a final "OIR-approved" approach for determining credits or rate differentials.

1. ***Step I. Model Design Code:*** Determine the model building code. For Group II buildings permitted up through and including 1982, use SBC 1976. For buildings permitted from 1983 through February 28, 2002, use SBC 1988. For buildings permitted on or after March 1, 2002, use FBC 2001. Group III have the same building code era dates as Group II. The only difference is that Group III buildings permitted from 1983 through February 28, 2002 use ASCE 1988 as the model building code.
2. ***Step II. Relativity:*** Use the following steps:
    a. ***Step A. Determine Base Relativity (R).***
        i. For a Group II building, determine the appropriate cell in Table 5-20 for Terrain B locations or Table 5-21 for Terrain C locations.
        ii. For a Group III building, determine the appropriate cell in Table 5-23 for Terrain B locations or Table 5-24 for Terrain C locations.
    b. Step B. Opening Protection Interpolation and Roof Cover Age Interpolation (if needed).
        i. Opening Protection Interpolation.
            3. If opening protection is none or hurricane, no interpolation is needed.
            4. If opening protection qualifies as Ordinary, OSB, Plywood, or Basic, use interpolation to compute R. Apply Equation 4-2 with the shutter interpolation factors (Factor 9) given in Table 5-11.
        ii. FBC Roof Cover Age Interpolation
            1. If an FBC roof cover is less than or equal to 5 years old, use the relativity from the FBC portion of the table and no interpolation is needed.
            2. If an FBC roof cover is tile, cement, slate or metal and is 20 years or older, or if it is any other material and 15 years or older use the non-FBC roof cover relativity and no interpolation is needed.
            3. For FBC roof cover ages between these limits, interpolate the relativity using Equation (4-3) with the A values from Table 5-11.
            4. Note that if opening protection interpolation is needed, then the FBC interpolation will require the use of opening protection interpolation values for both FBC and non-FBC roof covers.
    c. Step C. Apply Other Secondary Factors (Ki) to Produce Updated Relativity (R').
        i. Apply the secondary factors from Table 5-11 for the following features:
            1. Opening Coverage-All Openings
            2. Vinyl Siding
            3. Window/ Door Leak Potential
        ii. Apply the secondary factors for parapets and unrestrained rooftop equipment from Table 5-22 (Group II) or Table 5-25 (Group III).
        iii. Compute aggregate K factor from Equation (4-1b).
        iv. Compute updated relativity (R′) from K using Equation (4-1a).

3. ***Step III. Compute Rate Differential (D) or Credit (C):***
    a. This step is identical to Step IV in Section 6.4.1.

6.5.2 Example Calculations of Credits and Rate Differentials

We illustrate the calculation of rate differentials using the above steps for two cases.

a. ***Credit from Weakest Building-Case A.*** Group II building built in 1990 in Orlando (FBC design wind speed = 110 mph) in Terrain B with: no opening protection; non-FBC roof cover; concrete roof deck; no parapets; no inadequately-restrained rooftop equipment. The building has 20 units and an average of 4 double hung windows and 1 sliding glass door per unit.
    i. ***Step II A.*** The base relativity is looked up in Table 5-20 and R = 0.4061.
    ii. ***Step II B.*** No interpolation is needed since house does not have shutters and the roof cover is non-FBC.
    iii. ***Step II C.*** The only secondary factor that applies is No. 11 (Window/ Door Leak Potential). We perform the following calculation using the information in Table 5-11.
        1. The total count per unit for openings is 4 + 1 * 4 = 8, where each slider counts as 4 openings. There are 20 units in the building for a total of 160 openings.
        2. The K_i factor for all window types except casement and fixed for more than 30 openings is 1.14 for a building with no shutters. For most Group II and Group III buildings, the maximum values will apply since leaks from nearby units can affect the residence.
        3. We compute R′ using Equation (4-1a) according to $R' = 0.4061 * 1.14^{(1-0.4061)} = 0.4390$.
    iv. ***Step III.*** The credit from the weakest Group II building in Terrain B in the 101 to 110 mph FBC wind zone is simply C = 1-0.4390 = 0.5610 or 56.1%.

b. ***Credit from Weakest Building-Case B.*** Group III building built in 1980 in Orlando (FBC design wind speed = 110 mph) in Terrain B with: no opening protection; FBC roof cover (re-roofed in 2005); no SWR; metal roof deck; no parapets; and unrestrained rooftop equipment. The building has 60 units and an average of 2 double hung windows and 1 sliding glass door per unit.
    i. ***Step II A.*** The base relativity is looked up in Table 5-23 and R = 0.7532.
    ii. ***Step II B.*** No interpolation is needed since house does not have shutters and the roof cover is less than five years old.
    iii. ***Step II C.*** The only secondary factors that apply are No. 11 (Window/ Door Leak Potential) and No. 14 (Rooftop Equipment). We perform the following calculation using the information in Table 5-11.
        1. The total count per unit for openings is 2 + 1 * 4 = 6, where each slider counts as 4 openings. There are 60 units in the building for a total of 360 openings.
        2. The K_i factor for all window types except casement and fixed for more than 30 openings is 1.14 for a building with no shutters.
        3. The K_i factor for unrestrained rooftop equipment from Table 5-25 is 1.05.

4. The $c_o$mbined secondar$_y$ factor using Equation (4-1b) is K = 1.14*1.05 = 1.197.
5. We compute $_R$′ using Equation (4-1a) according to R′ = $0.7532*1.197^{(1-0.7532)}$ = 0.7874.

iv. ***Step III.*** The credit from the weakest Group III building in Terrain B in the 101 to 110 mph FBC wind zone is simply C = 1-0.7874 = 0.2126 or 21.3%.

c. Rate Differential: Case B.

i. Assume that the average relativity for Group III buildings in Terrain B in the 110 mph FBC wind zone has been estimated to be E(R) = 0.7215.

ii. Assume that the average Base Rate for windstorm losses to Group III buildings in Terrain B in the 110 mph FBC wind zone is $4.00 per thousand.

iii. The windstorm rate for the Case B Building = (0.7874/0.7215)*$4.00 =$4.37 per thousand.

7 Summary and Recommendations

7.1 Overview

A research project has been conducted to estimate the effects of wind-resistive building features in reducing hurricane damage and loss to single family and multi-family residential structures located in the state of Florida. This project is the first attempt to systematically update previously developed loss mitigation relativities (ARA, 2002a and 2002b). A major task in this project included the analysis of new data relevant to wind loss mitigation. This data includes insurance loss data from the 2004 and 2005 Florida hurricanes, damage survey data, and engineering data from laboratory tests and wind tunnel experiments.

The scope of this project has included construction prior to the introduction of the Florida Building Code 2001 (pre-FBC era) and post-FBC construction. To reflect wind-resistive design improvements implemented in the FBC, the post-FBC construction period includes two eras: FBC 2001 and FBC 2006 (i.e., the 2006 revisions to the 2004 FBC).

The results of this study are based on the analysis of individually modeled buildings at numerous locations in Florida. For post-FBC construction, the buildings were designed to the FBC 2001 and FBC 2006 according to the design wind speed, wind-borne debris region design options, and FBC definitions of Terrain Category. In the wind-borne debris region, the FBC 2001 era designs include both enclosed and partially enclosed structures, per the FBC and ASCE 7-98.

Each building has been modeled with a specific set of wind resistive features. There are two broad classes of buildings: single family houses and multi-family (5 or more units) residences. The multi-family residences include three groups, based primarily on building height and roof deck material: Group I (less than 60 feet tall with wood roof decks), Group II (less than 60 feet tall with non-wood roof decks), and Group III (more than 60 feet tall).

The loss mitigation features considered in this project are summarized in Table 7-1:

Table 7-1. Loss Mitigation Features

Single family and Group I Multi-family		*Groups II and III Multi-family*	
Features Considered in 2002	***Features Added in 2008***	***Features Considered in 2002***	***Features Added in 2008***
1. Terrain 2. Roof Shape 3. FBC, Non-FBC Roof Cover 4. Secondary Water Resistance 5. Roof-to-Wall Connection 6. Roof Deck Material/Attachment 7. Opening Protection 8. Gable End Bracing 9. Wall Construction 10. Wall-to-Foundation Restraint	1. Number of Stories 2. Roof Cover Material 3. Roof Slope 4. Soffit Construction 5. Vinyl Siding 6. Window/Door Water Leak Potential 7. FBC Roof Cover Age 8. Minimal Condition Requirements 9. Group I Only: Parapets and Rooftop Equipment	1. Terrain 2. Design Building Code 3. Design Windspeed 4. FBC, Non-FBC Roof Cover 5. Opening Protection 6. Roof Deck Material 7. Secondary Water Resistance	1. Parapets 2. Rooftop Equipment 3. Window/Door Water Leak Potential 4. FBC Roof Cover Age 5. Minimal Condition Requirements

The new features included in this study reflect knowledge gained from damage surveys and engineering data analysis. The minimal condition requirements include conditions for roof cover and

windows. These components should be in a reasonably good and repairable condition for the building to receive wind mitigation rate differentials. In addition, for wood roof decks, the roof deck strength must meet the minimal strength requirements for Deck Type A. Definitions and requirements for wind mitigation features are summarized in Appendix A.

The results of the wind mitigation analysis are presented in the form of "loss relativity" tables. These tables measure the loss reduction effectiveness of all possible combinations of the modeled wind mitigation features on a building. The tables provide a convenient way to "look-up" the effectiveness of wind mitigation features on any building, such as a two story gable house or a one story hip house with a tile roof cover. The loss relativities were developed such that they directly measure the difference in average annual insured loss for 2% deductible. Hence, the loss relativities can be used directly to compute insurance rate differentials on the wind premium. The rate differentials only apply to the portion of the wind premium associated with the dwelling, its contents, and loss of use (not any attached or detached structures or common deductible associated with such structures).

Significant reductions in loss are achieved on all building types when they have the appropriate wind mitigation construction techniques. While these reductions are similar in magnitude to the results obtained in the 2002 studies, the fact that this study includes more construction features results in a broader range of reduction, when measured from the weakest building. The loss reduction from the weakest modeled building is generally greater than 80% for single family and multifamily buildings. FBC construction era buildings also qualify for significant rate differentials, on the order of 70-85% for single family residences and 50% for Group II and III multifamily residences.

These results do not include recent research on terrain effects and wind borne debris, funded by the state. That research was being conducted under a separate project and did not get completed in time to meet the schedule requirements of this project. However, that work is now near completion and should be incorporated immediately into these results. It would address some of the shortcomings of this work and is essential to consistent set of wind loss mitigation relativities and a statewide uniform grading scale that is equally accurate in all parts of the state.

7.2 Summary and Conclusions

The following paragraphs summarize key elements of the research and results.

- ***Florida Locations.*** Eighteen locations in Florida were selected for the wind loss analyses. These points cover the windspeed regions and are generally located on the FBC wind contours. Each FBC wind contour and FBC design wind region contains at least one location point. A major consideration in the selection of the Florida locations was the new hurricane model results (see Section 2.3) vis a vis the current FBC wind map.
- ***Hurricane Wind Simulations.*** Five hundred thousand years of hurricanes were simulated for each Florida location.[40] These simulations were performed with an updated hurricane model that reflects updated boundary layer model, intensity model, filling rate model, Holland *B* parameter, and radius to maximum winds. The hurricane research and model updates were performed under previous projects, and have been presented to national code bodies, the FCHLPM, and the Florida Building Commission. The hurricane risks to Florida are reduced over the model results in 2002. These changes are most noticeable in the north central part of the State. The effect of this reduction may not be significant in terms of wind mitigation loss relativities since the average annual losses are normalized by location. We note that the significant amounts of new hurricane data have been factored into the model updates over the past 8 years. The updated windspeed

[40] Non-hurricane winds, such as thunderstorm winds, are important in the inland Big Bend area of Florida and tend to dominate the wind risk climate in this part of Florida. However, for the vast majority of the state, hurricane winds dominate the severe wind climate and, hence, are the appropriate windstorm to use for wind loss mitigation analysis.

risks in this report are based upon actual data (108 years of data from 1900-2007), and do not consider hypothetical future climate change/cycle effects, beyond the cycles reflected in past data.

- ***Florida Building Code Eras.*** There have been several major changes to the *FBC* since the 2001 *FBC* became effective in Florida on March 1, 2002. In 2004, a separate residential building code was introduced (*FBC Residential*). *FBC Residential* allows for prescriptive requirements to be used in a larger part of the state. *FBC Building* applies to nonresidential construction and construction of large multi-family residential buildings. Some of the key wind resistive improvements to the FBC include: removal of partially enclosed building design option, pressure requirements for soffits, ring-shank nails for roof deck attachment, options for 150 mph shingle, and changes to the WBD region in the Panhandle area of the state. We identified two FBC eras (date code changes went into effect) for purposed of analyzing wind mitigation loss relativities:

    1. FBC 2001 (March 1, 2002 to December 7, 2006)
    2. FBC 2006 (December 8, 2006 to present)

  The FBC 2006 era is based on the FBC 2004 with the 2006 Supplements. Building permit application dates determine the FBC era. Year built can also be used as an approximate surrogate for certain years. Refer to Section 2.2.4 for more details.

- ***Building Models and FBC Designs.*** A total of 44 building models were considered, including several new models of Florida residential buildings. Two model buildings were selected from each building class (one-story SF, two-story SF, Group I MF, Group II MF, and Group III MF). The engineering modeling of the designs of these buildings was performed for each building code era. The replacement costs of each building have been developed for a Florida location typical of the statewide average construction cost. The SF replacement costs range from $65 to $82 per square foot. For MF construction, the replacement costs range from $120 to $190 per square foot.

- ***Insurance Parameters.*** We analyzed the Florida Hurricane Catastrophe Fund (FHCF) exposure database for deductibles and coverage ratios for single family, condominium, and tenant policies. Based upon this review, we used 2% deductibles for the loss relativity simulations for both single and multi-family residential occupancies. For SF occupancies, we used 50% for the ratio of contents coverage to building coverage and 20% for the ratio of loss of use coverage to building coverage. For MF occupancies, we combined the FHCF commercial-residential, condominium unit owner, and tenant's policy exposures. This approach resulted in approximate MF coverage ratios of 30% for contents coverage relative to building coverage and 5% for loss of use coverage relative to building coverage.

- ***Insurance Policy Level Data Analysis.*** We analyzed data from eight insurance companies. These data include policy level data and claim folder level data. The policy level data includes 41 hurricane loss datasets. The Florida hurricanes included: Charley, Frances, Jeanne, Ivan, Dennis, Katrina, and Wilma. The key conclusions from the analysis of the insurance data include:

    1. Post-FBC (permitted after March 1, 2002) homes have significantly reduced losses (85%) compared to pre-FBC homes.
    2. Two-story homes, on average, have 31% higher losses than one-story homes, for both pre-FBC and post-FBC construction.
    3. Gable roof shapes have higher losses (14 to 28%) than hip roof shapes.
    4. Tile roof houses have 28% higher losses than shingle roof covers.
    5. Opening protection on windows significantly reduces losses (39%).
    6. Terrain roughness is an important parameter in hurricane losses. Houses located in Terrain B (suburban) have significantly reduced losses (49%) over houses located in Terrain C (open).
    7. Masonry-walled houses have lower losses than wood frame construction, but there are many confounding aspects of these data.
    8. Houses with several mitigation features have notably reduced losses (53-67%) over houses with no mitigation features.

Due to the limitation of the lack of high windspeed loss data and the limited number of policies with wind mitigation information available in these datasets, this insurance loss data can be used for general trend analysis only at this point. However, these results support the magnitudes of the wind mitigation loss relativities. A significant conclusion is that the loss relativities developed in 2002 for post-FBC construction appear to be generally reasonable, based on the insurance data analyzed to date.[41]

- ***Insurance Claim Level Data Review.*** A significant effort was put into the review of detailed claim folders, with particular emphasis on identifying the causes and extent of losses not associated with failure of the building envelope. The purpose of this review was to ensure that the wind loss mitigation rate differentials reasonably reflected losses for items not explicitly modeled in the analysis. Among these items are wind driven rain through cracks in windows and doors, damage to exterior accessories, losses from tree removal, and losses from attached and detached structures. Some of the key findings include:

    1. Non-building envelope losses were significant. These include losses from exterior accessories (components on the exterior of the building, including lights, exterior trim, roof vents, gutters, air conditioning units, power mast and drip wire, etc), interior loss without building envelope failure, tree removal, and tree debris removal. These losses were statistically modeled and considered in this study.
    2. Losses from damage to the roof cover dominate the losses for the claims reviewed. Improved modeling of repair and replacement costs and triggers for replacement were developed from the claim folder review. Roof age and condition significantly affect the repair vs. total replacement decision by the adjustor.
    3. Losses from attached and detached structures are significant. These structures need to be excluded from the determination of the portion of the wind premium to which the wind mitigation rate differentials is applied. In addition, these structures should have a separate deductible, which is what was assumed in developing the wind mitigation relativities in this study (2% deductible on dwelling losses, not including any losses from attached or detached structures).

- ***Building Damage Survey Data.*** Observations from the Florida hurricane damage surveys include:

    1. Post-FBC construction had reduced rates of damage/failure for roof sheathing, single doors, and sliding glass doors.
    2. Tile roof covers that were attached with nails/screws had about 50% less roof cover loss than tile roof covers attached with mortar.
    3. Gable-shaped roofs lost 33% more roof cover than hip roofs.
    4. Residences with no protection on the windows had “at least one damaged window” 5 times more likely than homes with window protection.
    5. Roof cover damage was much more extensive for pre-FBC houses and increased with age. Post-FBC houses experienced about ½ the roof cover loss of pre-FBC houses.
    6. Water penetration was reported for about ½ of the houses and there was little difference in pre-FBC and post-FBC houses.
    7. Seventy-nine percent of the houses with attached aluminum frame screen enclosures experienced catastrophic failure (collapse) in the highest wind area of Hurricane Charley.
    8. In Hurricane Ivan, homes located in heavily treed areas, experienced about ½ the losses of homes located in more open areas.

[41] This result is important since the 2002 loss relativities for post- FBC homes were quantified using models of homes designed to the then new FBC without the benefits of any loss or damage data to empirically validate the predicted level of loss reduction. Future work is needed to determine how much of the pre- *vs.* post-FBC loss difference is related to newer roof covers that haven’t aged or deteriorated appreciably.

- ***Engineering Data and Model Updates.*** New wind tunnel test data for single-family residential buildings (1 and 2 stories) with different roof shapes and roof slopes in different terrains were analyzed and incorporated into the modeling. These data provided significant updates to the determination of roof loads, including sloped and flat roofed buildings. A soffit damage model for single- and multi-family homes was introduced. A pressure driven water leakage model was developed for leaky windows and doors for both pre- and post-FBC buildings. The flat roof pressure model was updated to include parapet effects, base on recent wind tunnel test data. A rooftop equipment failure model was included for flat-roofed buildings. However, ongoing research on terrain and wind-borne debris was not included in this study due to the schedule requirements for this report.

- ***Loss Relativities for Single Family Houses.*** For pre-FBC houses, the determination of the appropriate wind loss mitigation relativity is based on the presence or absence of specific wind mitigation features. For single family homes, the look-up tables include 2,304 combinations in each of two Terrain tables. Fourteen secondary factors are included. For the assumed case of 2% deductible, the maximum loss reduction from the weakest house to the strongest house is 81% in Terrain B and 88% in Terrain C. New FBC construction qualifies for reductions in the 80% range in Terrain B and 85% in Terrain C. When measured against a typical house, the loss reductions for post-FBC houses are on the order of 50%. These reductions apply only to that portion of the wind premium associated with the dwelling, its contents, and loss of use. In addition, these reductions assume that any attached and detached structures have a separate deductible.

- ***Loss Relativities for Group I Multifamily Buildings.*** Group I buildings are typically 2-4 story wood or masonry frame structure with a wooden roof deck. The loss relativities for these buildings are very similar to those for single family homes. There are 1,224 pre-FBC loss relativities for each of the Terrain B and Terrain C tables. A total of 15 secondary factors can be applied to these relativities. The maximum loss reduction from the weakest building is 76% for Terrain B and 83% for Terrain C. The maximum loss reductions for post-FBC Group I buildings are about 78% in Terrain B and 84% for Terrain C.

- ***Loss Relativities for Group II and III Multifamily Buildings.*** Group II MF buildings are less than 60 feet tall and typically have flat concrete or metal roof decks. Group III MF buildings are 60 feet or more in height. The loss relativities for Group II and Group III buildings are based on the location (FBC wind zone and terrain) and building design era (pre-1983, 1983 to February 28, 2002, and after February 28, 2002). There are 234 loss relativities for each Group and Terrain. Four secondary factors can be applied to these relativities, including new factors for parapets and unrestrained or poorly restrained rooftop equipment. The maximum loss reductions range up to 80% for the strongest buildings in the lowest wind zones and up to 65% for the strongest buildings in the highest wind zones.

- ***Implementation.*** The implementation of wind mitigation rate differentials needs to be multi-faceted. The rate differentials need to be part of a program that:

    1. Requires accurate determination the presence/absence of wind mitigation features.
    2. Encourages building owners to invest in cost-effective mitigation to achieve lower insurance rates.
    3. Encourages insurance companies to collect wind mitigation data on their portfolio of buildings so that rates can be accurately determined.
    4. Provides for adequate and fair rates for insurance companies. The implementation of rate differentials should be a win-win situation for the insurance company and the building owner.
    5. Encourages reinsurance programs to reflect the actual distribution of wind mitigation features on an insurance company portfolio.
    6. Promotes continued improvements to the Florida Building Code.

If the rate differentials are implemented as credits from the weakest building, then the base rates should be adjusted to reflect the weakest building. Implementation of the rate differentials with offset calculations eliminates many problems, as discussed in Section 6.3. Since each 1% loss reduction achieved state wide reduces the average annual hurricane losses by 50 million dollars, the implementation should not include over-simplification of the loss relativities and secondary factors.

- ***Qualifications in the Application of Loss Mitigation Relativities.*** The following qualifications apply in terms of using the loss relativities to determine insurance rate differentials:

  1. The rate differentials apply only to the portion of the wind premium loss costs that covers the dwelling, contents, and loss of use. The loss relativities do not apply to that portion of the wind premium that covers attached or detached structures, even those that may be covered under Coverage A. Hence, insurance companies must determine how to allocate wind premium among dwelling-related losses and attached and detached structure-related losses.[42]
  2. The loss relativity rate differentials have been developed only for buildings that meet minimal standards of condition. These include:

     a. Roof Cover
     b. Openings
     c. Roof Deck

     Roof cover and openings (windows, doors, skylights, etc.) must be in reasonably good and repairable condition. Buildings with these components that in a state of notable disrepair should not qualify for rate differentials until the components are put into good condition. This note particularly applies to roof covers, which are a significant component of wind-related loss costs. Single-family residences and Group I multi-family residences must also have at least a roof deck strength that is Type A or better to qualify for wind mitigation rate differentials.
  3. The rate differentials developed in this report are strictly applicable only to 2% deductible cases and the insurance parameters discussed in Section 2.7.

7.3 Recommendations

Recommendations are grouped into two topics: short term updating of these loss relativities and longer term research needs.

Short Term Updating. We recommend that an immediate effort be undertaken to update these relativities before implementation in 2009 insurance rate filings. This short-term updating would include the following specific activities:

1. Integrate terrain and wind-borne debris research funded by the Florida Building Commission. The final phase of this work undertook a parallel path to the loss relativity research and was not completed in time for integration into this study due to mismatching schedules by a few months. However, that work is now available for integration and will significantly improve the results, allowing for more representative terrains to be treated in both coastal and inland locations. A dramatic impact on loss relativities is expected for inland locations in treed terrains.

[42] The impact of attached and detached structures is significant for all buildings, and particularly for strong single family residences. We simulated a case of an attached aluminum frame screen enclosure (10% of Cover A value) and found that the loss reduction was reduced by about ½ over the same building without the screen enclosure. Hence, since these structures are not built to the same requirements as the dwelling, they should be excluded from any rate differential applied to the wind premium. They should also have a separate deductible and not impinge on the dwelling deductible.

2. Address other improvements to the loss relativities, including:
    i. Refinement of definitions for roof shape by simulating hip roofs with different extent of gables to quantify a simple inspection rule for gable vs. hip roof shape and allow for interpolation between hip and non-hip relativities.
    ii. Refinement in definition of minimal roof deck strength by simulating missing nail cases and stapled roof decks. This will enable quantification for a simple inspection rule. Analysis of batten roof decks is also needed.
    iii. Regionalize pre-FBC tables for different wind zones and terrains in different parts of the state, using results from 1 above. This approach will avoid a major limitation of the single statewide table for pre-FBC single family and Group I construction. Much improved accuracy of the relativities is expected and a much smoother transition into the uniform grading scale.
    iv. Improve terrain determination for individual buildings.
    v. Include tree fall damage-induced losses to small buildings (single family homes).
    vi. Develop a factor for buildings designed/built to Terrain C loads but are located in Terrain B (e.g., inland HVHZ locations).
3. Determine if a separate set of tables for different insurance parameters is needed. Based on insurance company feedback, a separate case might include a different deductible, and/or combined deductible for separately-covered attached and detached structures. The loss relativities are notably dependent on the deductible assumptions.

Long Term Research. Long term research needs include the following work:

1. Improved roof-cover performance.
2. Water leakage through windows, doors, and walls.
3. Mitigation of tree fall damage.
4. Research on attached and detached structures, per recommendations in Twisdale, et al. (2007).
5. Determine if separate rating factor should be using for metal roofing systems.
6. Collection and analysis of insurance losses and damage data in strong hurricanes and different terrains.
7. Quantify quality of FBC construction to ensure FBC rate differentials can be granted without an inspection-based approach.
8. Allocation of losses between building owners and tenants or condominium association and condominium unit owners.

Other considerations include: the assessment of separate factors for porches and carports; variation of opening protection with building height for Group II and III buildings; roof edge systems for Group II and III buildings; and improved modeling of missile environment for large buildings; development of secondary factors for houses with attached garages that directly adjoin the interior living space and the main attic space; development of interpolation factors between the parapet and no parapet cases for building with flat roofs; treatment of attic separations (i.e., firewalls) in duplex, triplex, and quadplex buildings.

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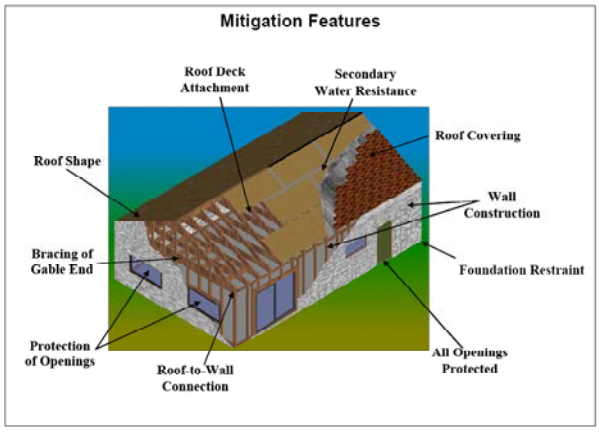

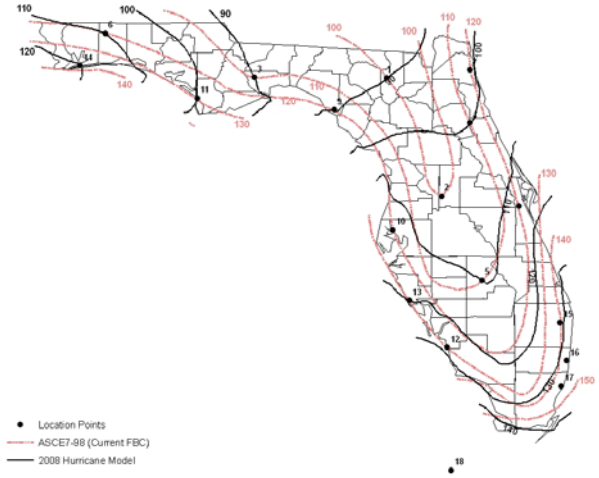

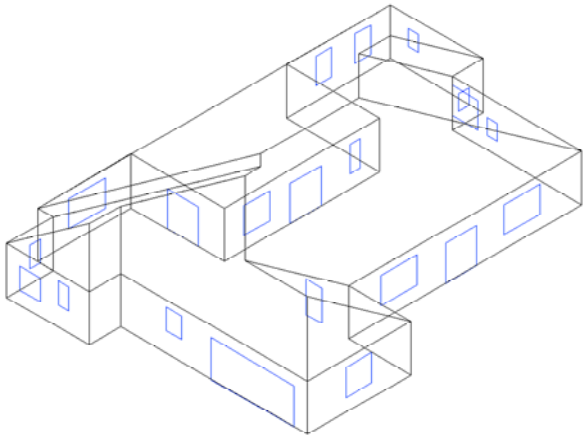

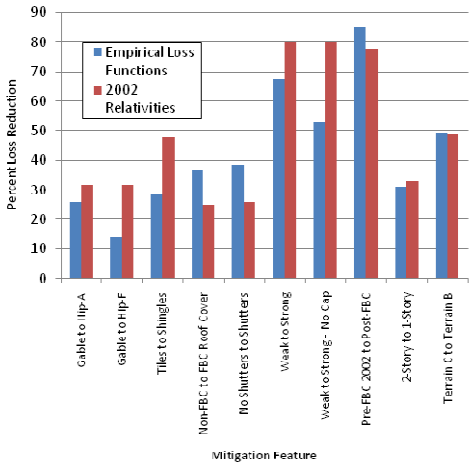

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Appendix A. Definitions of Wind Resistive Features

This appendix provides definitions for each of the wind resistive features evaluated in this study. The appendix is split into two main sections: (1) Single Family or Group I Multi-Family buildings and (2) Group II or Group III Multi-Family buildings. The flowchart in Figure A-1 defines the categorization of MF buildings with five or more units into Group I, II, or III. Sections A.1 and A.2 are further divided into primary factors and secondary factors.

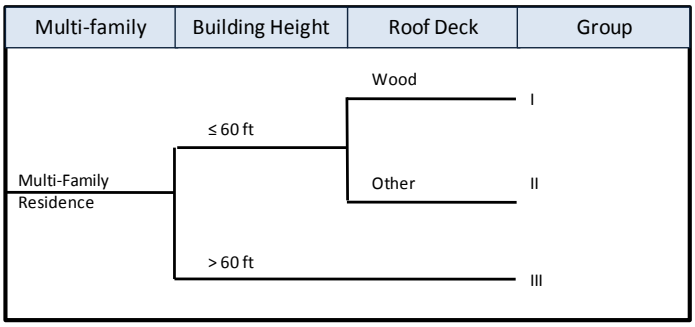


Figure A-1. Flowchart for Categorizing Multi-Family Buildings with Five or More Units

A.1. Single Family or Group I Multi-Family

Single Family (SF) Homes. Site-built residential dwellings with 1-4 units.

Group I Multi-Family (MF) Buildings. Residential buildings less than or equal to 60 feet high with 5 or more units and wood roof decks. These buildings are typically masonry or wood frame construction and one to four stories tall.

For SF homes and Group I MF residential buildings the following ***Building Code Eras*** are defined:

- ***FBC 2006.*** Buildings designed to the wind load provisions of the 2006 revisions to the 2004 Florida Building Code (FBC). This era includes buildings with permit application dates on or after December 8, 2006.
- ***FBC 2001.*** Buildings treated as being designed to the wind load provisions of the 2001 FBC. This era includes buildings with permit application dates between March 1, 2002 and December 7, 2006.
- ***Pre-FBC.*** All other buildings.

A.1.1. Primary Factors

The primary factors for pre-FBC SF and MF Group I buildings are listed in Table 4-4. The definitions for each primary factor are provided in the following sub-sections.

A.1.1.1. Terrain

The effects of terrain on building performance and hurricane losses are significant, but terrain remains a complex parameter for purposes of loss mitigation and insurance company rate differentials. There are several options for an insurance company to treat terrain. The reader is urged to review Sections 2.2.2, 4.2.3 and 4.2.4.3 for background information and discussion of options on treating terrain as a

building specific feature or as a rating territory feature. The loss relativity tables are self normalized to terrain and, hence the difference in loss costs for the same building in different terrains is not reflected in the loss relativity tables herein.

The basic options are:

1. ***Individual Building Terrain.*** Determine the terrain the building is located in using the ASCE 7 definition of terrain, which is given below. Given the terrain, use the appropriate terrain-based relativity table. Ideally, the insurance company would have different base rates that corresponded to different terrains.
2. ***Territory-Based Predominate Terrain.*** In this approach, the insurance company assigns the predominate terrain in a territory to all buildings in that territory. For example, coastal territories would be Terrain C and inland territories would be Terrain B.

Under Option 1, the insurance company uses the terrain assigned to the building from the mitigation inspection. Under Option 2, the insurance company would base the terrain on the territory in which the building is located. We recommend that the insurance company retain the individual building terrain in its database even if it uses Option 2.

For purposes of inspecting the building and classifying the terrain in which the building is located, the procedure needs to follow the accepted national standard, which requires determining the terrain for distances up to 2600 feet (or more for buildings taller than 130 feet) from the building. The approach involves determining if the building has sufficient obstructions (other buildings or trees) around it for the Terrain to be classified as Category B, otherwise the Terrain defaults to Category C.

Terrain is defined in terms of ASCE 7-05 and Section 1609.4 of the Final Draft of the 2007 FBC:

- ***Exposure Category B.*** Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger. For buildings whose mean roof height is less than or equal to 30 feet, these conditions must prevail for an upwind distance of 1500 feet. For buildings whose mean roof height is greater than 30 feet but less than 130 feet, these conditions must prevail for an upwind distance of 2600 feet. For buildings whose mean roof height is greater than or equal to 130 feet, these conditions must prevail for an upwind distance of 20 times the height of the building.
- ***Exposure Category C.*** Open terrain with scattered obstructions having heights generally less than 30 feet. This category includes flat open country, grasslands, and shorelines and shall extend downwind for a distance of 1500 feet. This category shall also apply to any building located within 100 feet horizontally in any direction of open areas of Exposure C-type terrain that extends more than 600 feet and width greater than 150 feet in the upwind direction.

For the purposes of determining loss relativities, the terrain shall be determined for eight sectors of 45 degrees each. If the terrain is determined to be Exposure Category B in all eight sectors, the building site shall be classified as Terrain B. If the terrain is determined to be Exposure Category C in one or more of the eight sectors, the building site shall be classified as Terrain C.

A.1.1.2. Roof Shape

There are many common roof shapes in residential construction. Gable and hip are the most common, although flat, Dutch hip, gambrel, mono slope, and many shape combinations are possible. Figure A-2 illustrates some of these shapes. Gable roofs have vertical walls that extend all the way to the top of the inverted V. A pure hip roof has sloping ends and sloping sides and horizontal eaves around the full perimeter of the building.

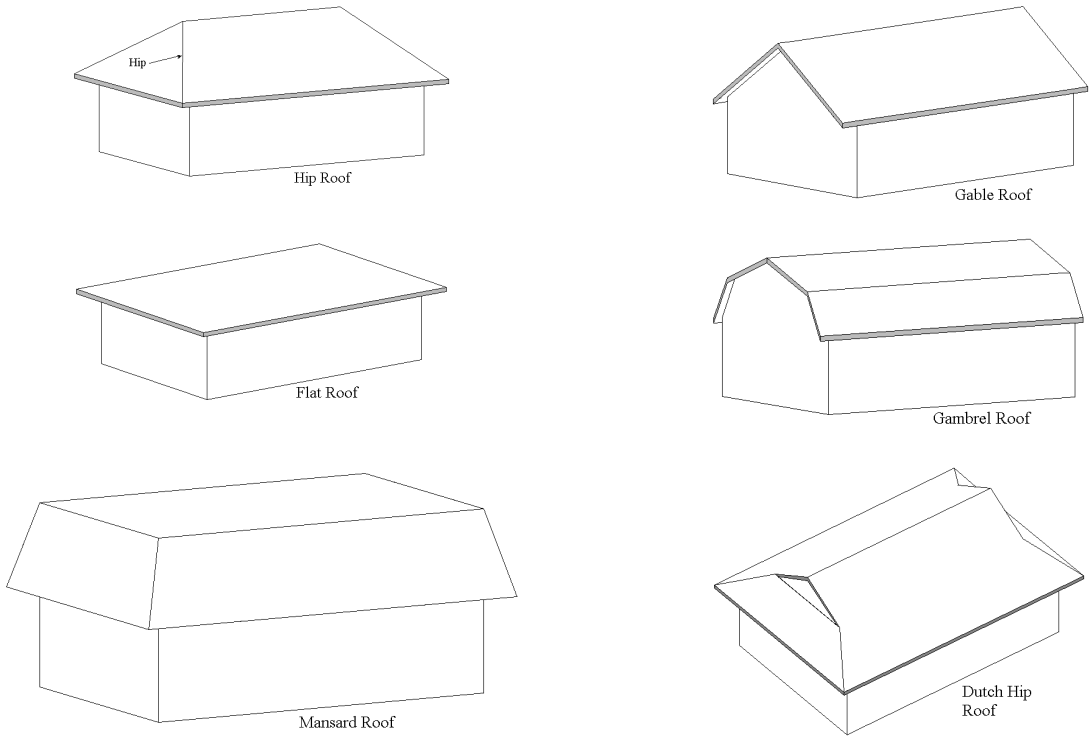


Figure A-2. Roof Geometry Shapes

Roof shape determines the aerodynamic pressure loads experienced by the roof due to wind flow and wind direction. For some wind directions, the maximum uplift loads on gable roofs are almost twice those of the hip at the locations with the highest negative pressures. Hence, with the same deck nailing pattern and roof covering, gable roofs will experience more damage than hip roofs.

For practical reasons, we consider only two basic roof shapes for SF homes in this study: hip and other (other is analyzed as gable). For Group I MF buildings, we consider three basic roof shapes: hip, gable, and flat. For classification purposes, the gable classification can be thought of as "other". That is, for SF homes, a roof is either a hip roof, per the definition given below, or it is in the "other" category. For Group I MF buildings, a roof is either a hip roof or a flat roof, per the definitions given below, or it is in the "other" category.

In classifying the roof shape of a building, we are concerned with the ***main roof sections*** that cover the attic space (if any) and the exterior wall envelope[1] of the building. Separate, secondary roof sections that cover only exterior spaces such as porches or carports are not considered in determining the roof shape. Architectural elements that are completely isolated from the attic or living space by the roof decking (e.g., a decorative dormer constructed completely outside the main roof deck) are also excluded from consideration.

[1] Exterior Wall Envelope: A system or assembly of exterior wall components, including exterior wall finish materials, that provides protection of the building structural members, including framing and sheathing materials, and conditioned interior space, from the detrimental effects of the exterior environment [Source: 2007 FBC, Section 1402].

- ***Hip Roof.*** The main roof sections of a hip roof must be sloped all the way down to horizontal eaves over at least 90% of the perimeter of the exterior wall envelope. To qualify, the total horizontal length of all non-hip roof sections (including dormers, gables, Dutch hip gables, flat sections, mansards, etc.) must be no greater than 10% of the perimeter of the exterior wall envelope.[2]
- ***Flat Roof.*** At least 90% of the main roof area of the building has a slope of less than 2:12.
- ***Other Roof.*** For SF homes, any roof that does not qualify as a Hip Roof. For Group I MF buildings, any roof that does not qualify as either a Hip Roof or a Flat Roof.

Insurance classification procedures for roof shapes are best developed with many example photos and supporting discussion/rules to ensure accurate ratings. Because the relative difference in hurricane losses for roof shape is significant, roof shape ratings should be done as accurately as possible.

A.1.1.3. Roof Covering Type

There are several common roof coverings used in residential construction. For sloped roofs, tiles and asphalt shingles are the most common materials; however, metal panels, wood shakes, and other materials are also used.

For practical reasons, we consider only two basic roof coverings for sloped roofs in this study: tile and shingle. Tile roofs are different from shingle roofs in several important respects. First, they provide added mass to the roof, reducing the effect of the uplift forces. This added self weight (8-10 psf) can significantly reduce the wind induced uplift loads acting at the truss-wall connection, reducing the likelihood of whole roof failures. Thus, the loss relativity value for stronger roof wall connections for tiled roofs is less than that for shingle roofs. Second, however, tile roof covers are much more vulnerable to debris impact damage and are also more expensive to replace. These factors make tile and other heavy roof covers a distinct class. The method of attachment of tile roof covers is also a key consideration if an insurer chooses to rate tile roofs distinctly.

For classification purposes, the shingle classification can be thought of as "non-tile". That is, for SF homes and Group I MF buildings with sloped roofs, a roof covering is either tile, per the definition given below, or it is in the "non-tile" category.

- ***Tile Roof Coverings.*** Any type of overlapping clay, concrete, or stone tiles. Tiles are typically rectangular in shape and can be either flat or curved. To qualify as a tile roof covering, at least one third of the main roof area must be covered with tiles.
- ***Non-Tile Roof Coverings.*** For buildings with sloped roofs, any roof covering that does not qualify as a tile roof covering.

A.1.1.4. Roof Cover Strength and Condition

A key factor in roof covering performance is the method of attachment of the roof covering to the roof deck. The most common roof covering materials in Florida are asphalt shingles and tiles. Other roof covering materials used for residential construction in Florida include built-up, metal, slate, wood shakes, and single ply membranes.

For classification purposes, roof cover strength is classified as either FBC Equivalent or Non-FBC Equivalent:

[2] For a Dutch hip roof, the length of the base of each vertical triangular face should be counted as if it were resting on the exterior wall even though it is set back from the exterior wall.

- ***FBC Equivalent.*** Any roof covering meeting the material requirements and attachment specifications of the FBC Chapter 15 (FBC 2001 or later) or the 1994 SFBC. For asphalt shingles, these requirements include improved self-seal strips and compliance with ASTM D-3161 (Modified for 110 mph). This requirement is commonly referred to as the "110 mph" rated shingle. The rating of roof covering for existing construction can be certified by requiring the roofing contractor to certify that the installation met the 1994 SFBC or the FBC 2001 requirements.
- ***FBC 2006 Shingle Roof Covers.*** The 2006 supplement to the FBC 2004 included an option for the ASTM D-7158 Class H (150 mph) shingle for wind zones ≥ 130 mph. For purposes of applying the FBC 2006 loss relativity tables for FBC 2006 buildings with shingle roof covers, the FBC 2006 shingles must meet the optional requirements of ASTM D-7159 Class H shingles. If FBC 2006 buildings located in ≥ 130 mph wind zones have shingles that do not meet the ASTM D-7159 Class H specifications, then the FBC 2001 loss relativity tables should be used for FBC 2006 shingle roof cover construction. This determination may require review of the construction plans/specifications and/or by separate affidavit. Also, refer to Section 2.2.4.8 and Section 4.3.1 and Figure 4-7.
- ***Non- FBC Equivalent.*** Any roof covering that does not qualify as FBC Equivalent or FBC 2006 Shingle Roof Covering.

Figure 4-7 provides a decision tree to help determine which set of FBC relativity tables to use for SF and Group I multi-family buildings.

Minimal Conditions. If the building has a degraded roof cover in poor condition, it cannot qualify for any mitigation rate differentials (regardless of what other mitigation features are on the building) until the roof cover is replaced. The rationale behind this requirement is that the loss relativities are so dependent on the roof cover that an entire table of relativities would need to be developed for poorly-conditioned roof covers.

Shingle roofs with any of the following deficiencies shall not meet the minimal condition for eligibility for roof cover related insurance discounts:

- Any missing shingles or tabs
- Significant cupping of the shingle tabs
- Singles/tabs not sealed to the layer below
- Granule loss to the point where you can see a smooth surface on the top of the shingles
- Cracked or broken shingles

Tile roofs with any of the following deficiencies shall not meet the minimal condition eligibility for roof cover related insurance discounts:

- Missing tiles
- Loose tiles
- Cracked or broken tiles

Other types of roof cover systems (metal, wood, etc.) that have either (1) missing, loose, or damaged elements, or (2) missing, corroded, or inadequate fasteners shall not meet the minimal condition requirement.

A.1.1.5. Secondary Water Resistance

Secondary water resistance (SWR) is a layer of protection that seals to the roof deck and protects the building if the roof covering and underlayment fail. This mitigation technique is aimed at keeping rain

water out of the house once the roof covering fails. SWR covers or seals the seams in the roof deck and provides a redundant layer of water proofing.

The most economical way to achieve SWR is to apply Self-Adhering Modified Bitumen Tape to the plywood joints. This self-adhering tape is generically known as Ice & Water Shield or Peel N Seal and is a rubber-like product applied directly to a roof deck to prevent damage from ice dams in northern climates. Here, the product is applied to the outside of a clean plywood/OSB deck prior to application of regular underlayments and roof covering. The most economical use of this product is to use 6″ widths as shown in Figure A-3. This is done when a new roof covering is being put on the house.

Another way to achieve SWR is a foamed polyurethane structural adhesive applied from inside the attic to cover the joints between all plywood sheets. Figure A-4 shows this product installed in an attic. Note that this product is also used to reinforce the connection between trusses and roof sheathing, qualifying for improved roof deck attachment. Structural adhesives that meet AFG-01 should not be confused with foamed insulating products.

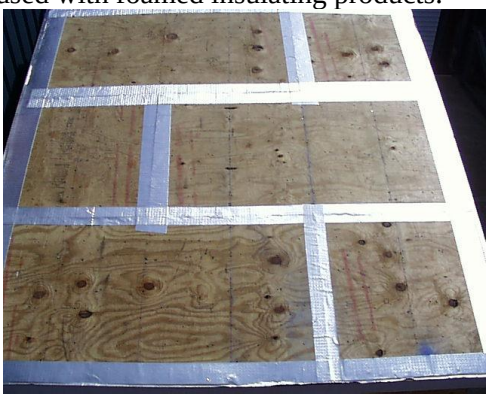


Figure A-3. Self-Adhering Modified Bitumen Strips Applied to Plywood Joints of Roof Deck



Figure A-4. Sprayed on Structural Adhesives to Seal Plywood Joints (SWR) and Strengthen Roof Deck Attachment

The verification of externally applied SWR must be done at the time of application since once covered, it is difficult to verify. The foamed structural adhesive applied from inside the attic, however, is readily verified with an attic inspection. Roofing contractors should complete a form to provide certification for the owner in order to receive this credit.

Standard roofing underlayments or hot-mopped felts do not qualify for SWR because they may be blown off the roof deck at high wind speeds. In contrast, off-the-shelf self-adhering bitumen tape has been tested to negative pressures of over 150 psf without failure of the SWR strips. The use of SWR in this study assumes that the waterproofing is self-adhering to the roof deck and will not fail when the roof cover fails.

A.1.1.6. Roof-to-Wall Connection

The roof-to-wall connection keeps the roof on the building by transferring uplift loads on the roof into the supporting walls. Verification of the type of roof-to-wall connection requires access to the attic.

For practical purposes, a classification is used herein to distinguish the uplift capacity of roof-to-wall connections based on connector type.

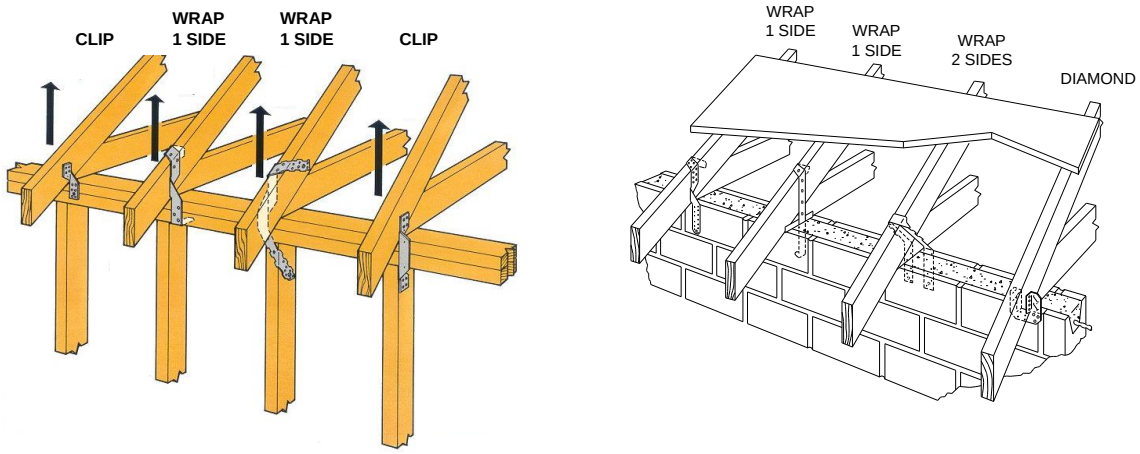
- ***Toe Nails.*** Typically three nails driven at an oblique angle through the rafter and into the top plate. An example of a toe-nail connection is shown in Figure A-5.

- ***Clips or Non-Wrapped Straps.*** Metal clips or non-wrapped straps nailed into the side of the rafter/truss and into the side of the top plate or wall stud. The metal does not wrap around the top of the rafter/truss and is typically only located on one side of the connection. A diamond clip is a special type of clip that has a slot in the middle to accept the rafter, and nails to the outside edge of the top plate. At least three fasteners are needed to transfer the loads at each end of the clip and the fasteners must always be loaded in shear (perpendicular to the nail direction). Non-wrapped straps may be embedded into the bond beam of a masonry wall. Clips or non-wrapped straps must be installed at every rafter/truss, and there must be not be severe corrosion visible.
- ***Single Wraps:*** Metal straps attached to the side and/or bottom of the top plate and nailed to the rafter/truss. At least three fasteners are needed to transfer the loads at each end of the strap and the fasteners must always be loaded in shear (perpendicular to the nail direction). The strap may be embedded into the bond beam of a masonry wall. In this case, the point of embedment must be within 1.5 inches of the rafter/truss. Straps must be installed at every rafter/truss, and there must be not be severe corrosion visible.
- ***Double Wraps:*** Metal straps attached to the side and/or bottom of the top plate on either side of the rafter/truss and wrapped over the top of the rafter/truss. At least three fasteners are needed to transfer the loads at each end of the strap and the fasteners must always be loaded in shear (perpendicular to the nail direction). The strap may be embedded into the bond beam of a masonry wall. In this case, the point of embedment must be within 1.5 inches of the rafter/truss. Straps must be installed at every rafter/truss, and there must be not be severe corrosion visible.

There are several manufacturers of metal connectors for hurricane uplift connectors and each company has a fairly wide line of products. Several examples are shown in Figure A-6.



Figure A-5. Example of a Toe-Nail Connection Used for Rafter-to-Top Plate Connection



(a) Wood Frame *(b) Masonry*

Figure A-6. Typical Hurricane Roof-to-Wall Metal Connectors

Typical design strengths and ultimate strengths for the four roof-to-wall connection types are summarized in Table A-1. The uplift resistance capacities are mean ultimate values based on tests results. The ultimate values are distinctly different from the design value of the connection. For example, a 386 lb rated clip has an ultimate capacity of about 866 lbs. The ultimate values are the mean failure values used in the loss relativity calculations.

Table A-1. Roof-to-Wall Connections Analyzed for Loss Relativities

Description	*Typical Design Strength* (lbs)*	*Mean Ultimate Strength Used in Calculations (lbs)*
Toe Nail (3-16d)	185	415
Clip	386	866
Wrap	535	1200
Double Wrap	891	2000

* Includes 60% increase for wind loading

Some of the older straps found in Florida are simply strips of galvanized metal that were pounded into shape on site to perform the same functions as the straps shown here. These galvanized straps were

often 1″ by 1/8″ thick pieces of galvanized steel. If these straps are installed correctly and are not compromised by corrosion, they will perform adequately.

A.1.1.7. Roof Deck Attachment – Plywood or OSB Roof Decks

Roof decks SF and Group I MF buildings are typically constructed with plywood, OSB, dimensional lumber, tongue and groove boards, or battens. The most common roof deck types are plywood and Oriented Strand Board (OSB) decks. Secondary factors have been developed for dimension lumber roof decks, concrete roof decks, and enhanced roof decks which are defined in Sections A.1.2.1, A.1.2.6, and A.1.2.7 respectively.

By far the most important feature of roof decks is the attachment to the framing, which is usually achieved by nail fasteners. Nail size, type, spacing, and penetration depth into the truss or rafters determines the uplift resistance of the deck. The difference in uplift capacity of 8d (2½″) nails at a typical nail spacing and 6d (2″) nails at the same spacing is a factor of about two times stronger, which makes a significant difference in deck performance in hurricanes.

The thickness of the deck material is important primarily in the determination of the penetration depth of the nail into the truss/rafter. Prescriptive building codes specify longer nails for thicker decks. Thicker decks have an added advantage of adding additional weight to the roof which helps to resist whole roof failures. However, thicker decks by themselves do not make a notable difference for deck attachment failures as these are governed by local pressures. The effect of deck thickness is treated as a secondary factor (see Section A.1.2.8).

For existing construction, the only practical way to determine deck type and fastener type and spacing is by a trained inspector going into the attic. We have analyzed roof deck attachments for the following cases:

- ***Roof Deck Attachment Level A.*** Plywood/OSB (minimum thickness of 7/16”) nailed with 6 penny common nails at 6″ spacing on the edge and 12″ in the field on 24″ truss spacing. This provides for a mean uplift resistance of 55 lbs per square foot. To qualify for Level A, the average number of missed or side-splitting nails over a 48” length must be three or less.
- ***Roof Deck Attachment Level B.*** Plywood/OSB (minimum thickness of 7/16”) nailed with 8 penny common nails at 6″ spacing on the edge and 12″ in the field on 24″ truss spacing. This provides for a mean uplift resistance of 103 lbs per square foot. To qualify for Level B, the average number of missed or side-splitting nails over a 48” length must be three or less.
- ***Roof Deck Attachment Level C.*** Plywood/OSB (minimum thickness of 7/16”) nailed with 8 penny common nails at 6″ spacing on the edge and 6″ in the field on 24″ truss spacing. Within 4′ of a gable end the nail spacing is 4″. This provides for a mean uplift resistance of 182 lbs per square foot for non gable end locations and 219 lbs per sq foot for gable end locations. To qualify for Level C, the average number of missed or side-splitting nails over a 48” length must be three or less.

Minimal Conditions. Any plywood or OSB roof deck that does not meet the minimum requirements for Level A does not meet the minimal condition requirements for roof deck strength. Buildings with less than Strength A cannot qualify for any mitigation rate differentials (regardless of what other mitigation features are on the building) until the roof deck attachment is brought up to at least Level A. Of course, we recommend that all decks be brought up to at least Strength C given the opportunity to add additional fasteners.

The panel uplift resistances given above are based on a combination of experimental data obtained from individual nail withdrawal tests and laboratory uplift tests performed using full sizes (4′ by

8′) sheets of plywood and OSB. Note that the uplift resistance of a panel is dependent upon the species of wood of the underlying truss or rafters and the moisture content of the wood. Decks attached with screws and or adhesives should be rated according to the equivalent uplift resistance of these attachments using the categories above.

Based on the RCMP and FWUA inspections in Florida, more than about 60% of the existing roof deck/attachments will be superior to Level A (6d nails at 6/12 spacing).

There are many technical issues that affect the proper rating of the roof deck (see Figure A-7), including a great variety of available nail sizes, nail penetration depths, the consideration of missed nails, etc. Proper inspection guidelines and training are essential to determining the deck attachment of existing residences.

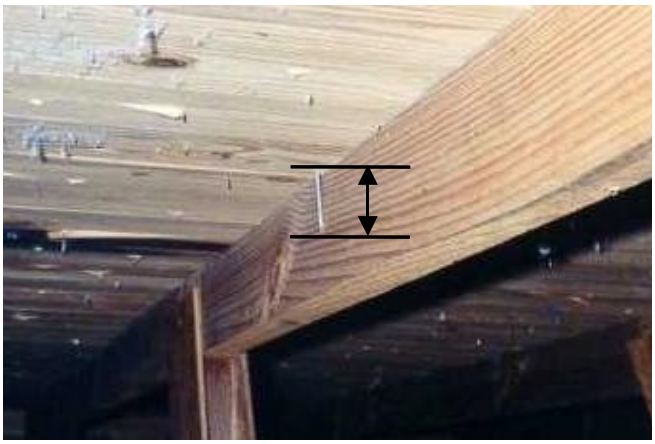


Figure A-7. Roof Deck Attachment Rating Requires an Attic Inspection.

Batten deck is a system where boards are laid perpendicular to the rafters and spaced apart from each other. This deck forms the basis for which to install wood shakes or wood shingles. There is no continuous deck in this roofing system. Batten decks with wood shakes have not been analyzed separately in this study. An interim recommendation is to use Roof Deck Attachment Level B.

A.1.1.8. Opening Protection – None vs. Hurricane

Openings in the wall and roof include windows, doors, sliding glass doors, skylights, and garage doors. Gable end vents and other roof vents are not considered openings for purposes of this study. Openings are vulnerable to wind-borne debris impacts in hurricanes and other windstorms. Typical single and double strength glazing are easily broken by impact from light weight debris that is generated from roof covering failures during high winds. In addition, heavier debris, such as roof tiles, 2″ by 4″ wood members, and plywood will easily penetrate openings that are not protected by impact resistant products.

The protection of openings is perhaps the greatest single loss mitigation strategy for a building. Once a window or door fails, the pressure inside of the structure increases due to the breach in the building envelope. The positive pressure inside of the building produces an additive load on the building envelope. The increase in load can be up to twice the loads the building experiences without a breach of the envelope. This approximate doubling of the load can easily put the roof, other windows, doors, in an overload situation. The result is often additional failures that occur after the original opening fails.

The first building code to adopt opening protection requirements in the United States was the South Florida Building Code in 1994. The testing protocol in this code requires the protection device to

withstand impacts by 2 by 4 studs followed by pressure cycle loading. The Standard Building Code's SSTD-12 has similar requirements. In 1999, the ASTM also came out with a debris impact standard (E 1996) and test (E 1886). These standards include requirements for both wind pressure and debris impact. Opening protection products manufactured before 1994 would not have been tested to these standards. Figure A-8 shows an example of opening protection with the Miami-Dade County sticker showing product compliance with test standards.

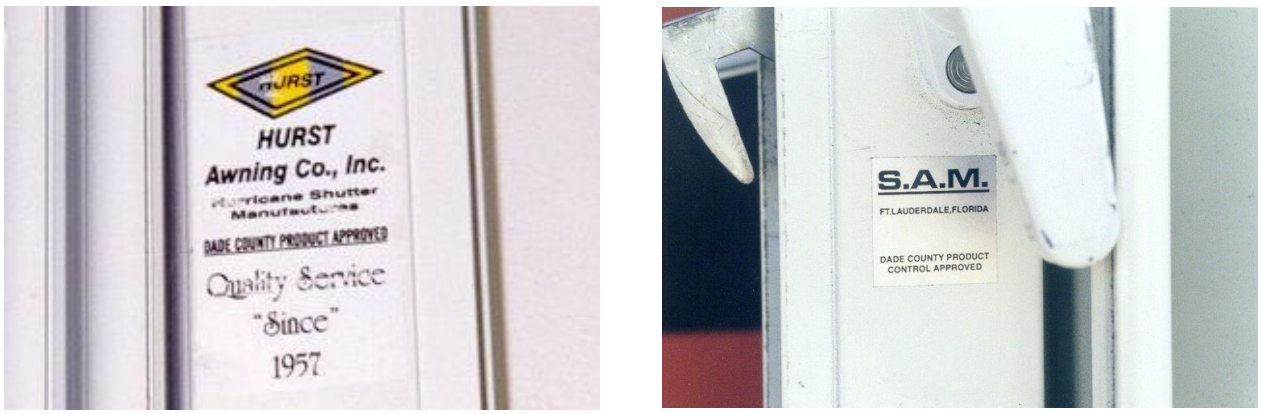


Figure A-8. Two product approval sticker on accordion shutters indicating that they meet Miami-Dade County impact resistance and wind pressure load standards. These labels contain the words "Dade County Product Approved" or equivalent.

For this study, the primary levels of opening protection are:

- ***Hurricane.*** All glazed openings impact resistant or protected with an impact resistant covering meeting the requirements of SSTD 12, ASTM E 1886 and ASTM E 1996, or Miami-Dade TAS 201, 202, and 203. Note that outside the HVHZ, skylights need only be protected to ASTM Missile Level B (4.5 lb 2" × 4" missile).
- ***None.*** One or more glazed opening not protected to the Hurricane level protection.

Minimal Conditions. All openings (windows, doors, and skylights) must be in good condition. Openings that are in disrepair (or have large gaps) will allow large amounts of water (from the wind-driven rain within a hurricane) to enter the building without the window or door actually failing from pressure or missile loads. While shutters over these opening may act as a rain screen and thereby help reduce the amount of water leakage in a hurricane, the loss relativities were not developed for buildings with openings in a state of disrepair or needing replacement. Buildings with openings that are in need of replacement do not qualify for wind mitigation rate differentials, regardless of the presence/absence of other features.

Intermediate levels of opening protection (OSB, Plywood, Ordinary, and Basic) are defined in Section A.1.2.8. Each intermediate level requires that all glazed openings be protected to at least that level.

A.1.1.9. Roof Slope

Roof slope is a key factor in determining roof loads which directly impacts the level of roof covering damage, roof deck damage, and whole roof failures.

For classification purposes, sloped roofs are defined as either Low Roof Slope or High Roof Slope:

- ***High Roof Slope.*** At least two thirds of the main roof area has a slope of 6:12 or steeper.
- ***Low Roof Slope.*** For single-family homes, a roof that does not qualify as a High Roof Slope. For Group I buildings, a roof that is neither Flat (see Section A.1.1.2) nor High Roof Slope.

A.1.1.10. Soffits

Prior to the 2006 revisions to the 2004 FBC, there were no design requirements for soffits. Therefore, for the pre-FBC and FBC 2001 building code eras, soffit material is a key factor in determining the likelihood of soffit failures. Soffit failures can result in water infiltration into the attic space and pressure changes in the attic space.

For classification purposes, soffit material is defined as either Wood or Other:

- ***Wood Soffits.*** All soffits that are constructed with plywood, OSB, solid wood, or fiber cement siding products. To qualify as wood soffits, the wood soffits must be in good condition (no visible evidence of rotting or sagging) with adequate fasteners.
- ***Other.*** Soffits that do not qualify as wood soffits.

Buildings with both wood and other soffits should be classified as "other."

A.1.1.11. Number of Stories

The SF houses used in this study are either one- or two-story buildings. One- and two-story residences generally fall into building heights less than 30 feet and the loads on the buildings are very sensitive to the building height. Significant differences in loads can result between buildings 15 feet tall and 25 feet tall because of the exponential nature of the vertical wind profile. SF homes greater than two-stories in height should use the two-story relativities.

For classification purposes, the number of stories for a SF home is defined as follows:

- ***One-Story.*** A SF home with a mean (horizontal) eave height less than or equal to 13 feet above local grade. The mean (horizontal) eave height shall be computed at four perimeter corners of the building. The average of the (horizontal) eave heights must be less than or equal to 13 feet for the building to be classified as one story.
- ***Two-Story.*** Any SF home that does not qualify as One-Story.

Eaves are defined as the external horizontal overhang of a roof over a wall of a building. The eave height is measured at corner locations that tend to bound the footprint of the building, as illustrated in Figure A-9. If the roof does not overhang the walls, the eave height is defined as the point where the roof wall horizontal intersection begins. The eave height is measured from the bottom of the eave to the ground. For corners with no eave, the measurement shall be made to where the roof surface intersects the wall.

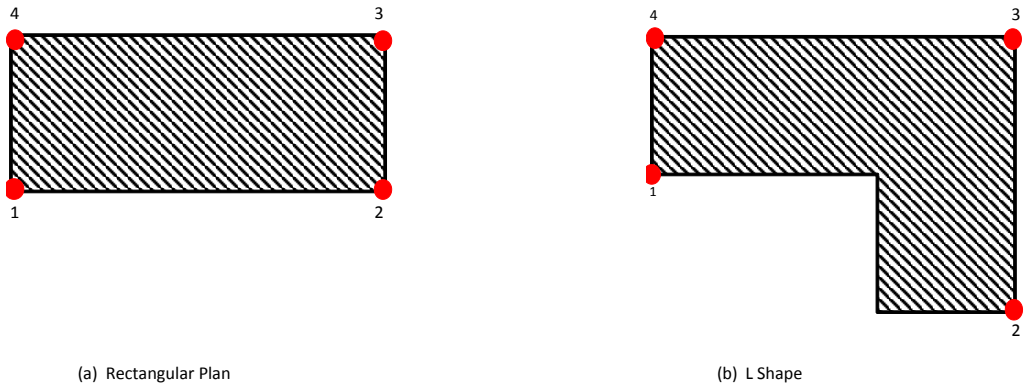


Figure A-9. Example Locations of Corner Eave Height Measurement for Determination of Number of Stories.

Number of stories is not a rating factor for MF buildings. The model MF Group I buildings used in this study are two-story buildings.

A.1.2. Secondary Factors

The secondary factors for pre-FBC SF and MF Group I buildings are listed in Table 4-15. The definitions for each secondary factor are provided in the following sub-sections.

A.1.2.1. Dimensional Lumber Deck

Prior to the availability of plywood and oriented strand board (OSB), the most common roof decking material was dimensional lumber or tongue and groove (T&G) boards. Because of the inherently large number of nails in dimensional lumber or T&G, the uplift capacity is generally far greater than typical plywood/OSB decks.

- ***Dimensional Lumber and Tongue and Groove Decks.*** A main roof deck that is 100% sheathed with solid wood dimensional lumber or T&G boards. The boards are usually 4″ to 8″ wide and nominally 1″ thick (¾″ actual thickness) and are laid in a fashion that is parallel to the ridge or diagonal to the ridge. The boards must be fastened with at least two 8d nails per truss/rafter connection.

We have analyzed the case of two 8d nails per board, producing a mean uplift resistance of 338 lbs per square foot.

A.1.2.2. Unreinforced and Reinforced Masonry Walls

The most common types of wall construction used for SF and Group I MF residential construction are wood frame, masonry, and combinations of the two. The different construction materials are important for fire resistance considerations, but are less important for wind resistance. Masonry walls are further distinguished by whether or not there is steel reinforcing to carry vertical and horizontal loads.

Insurance companies have generally rated buildings by wall construction material. However, it is likely that there are many rating errors since wood frame buildings with brick veneer may have been incorrectly rated as masonry walls. Also, many homes in Florida have an exterior stucco finish, which can be applied over a number of wall construction materials, including masonry, wood frame, insulated concrete forms, etc. Therefore an important consideration for insurers is whether or not to accept the wall construction information they may have in their database or obtain an updated wall construction

certification as part of the overall procedure to determine the proper building class based on all the important wind-resistive rating features.

- ***Reinforced Masonry or Concrete Wall Construction*** has at least two thirds of the exterior wall area constructed of masonry or concrete materials that are reinforced with both vertical and horizontal steel reinforcement and are relied upon for structural stability. It is important that the vertical reinforcement is fully grouted in the hollow cells of Concrete Block Masonry Units (CMUs), and that horizontal reinforcement be fully grouted in specially formed units. Tilt-up or poured concrete wall units must be reinforced with both vertical and horizontal steel reinforcement. The existence of reinforcing steel must be verified with a metal detector at a minimum of three locations, including at least two corner locations and at least one window or door location. The walls may be left unfinished, stuccoed, or have a veneer system hung from the walls.
- ***Unreinforced Masonry Wall Construction*** has at least two thirds of the exterior wall area constructed of masonry materials that do not meet the reinforcing requirements of Reinforced Masonry Construction. The walls may be left unfinished, stuccoed, or have a veneer system hung from the walls.
- ***Framed Wall Construction*** is composed of a stick frame made from wood or metal studs and is often sheathed with plywood or Oriented Strand Board (OSB) upon which an exterior wall covering is installed. Any SF or Group I MF building that does not meet the requirements of Reinforced Masonry or Concrete Wall Construction or Unreinforced Masonry Wall Construction should be classified as having Framed Wall Construction.

There are inspection techniques that can distinguish frame, masonry, and reinforced masonry wall construction. With appropriate training, an inspection of an existing building can accurately determine the proper classification of reinforced masonry versus masonry.

The model houses analyzed in this study were either all masonry, all wood frame, or all reinforced masonry. We did not analyze mixed masonry-wood construction. In general mixed construction consists of masonry first floors and wood frame second floors. A conservative rule is to classify the building as wood frame if wood construction is more than one third of the exterior wall construction of the building.

A.1.2.3. Opening Protection Coverage – All Openings Protected

The analyses performed herein for opening protection are for two extents of protection:

- ***All glazed openings protected***. A glazed opening refers to glass or a transparent or translucent plastic sheet used in windows, doors, or skylights (ASCE 7-98 and later editions). For this case, entry doors and garage doors that do not contain glazing may be unprotected.
- ***All openings protected.*** For this case, all openings, including all non-glazed entry doors and garage doors, must be protected to "Hurricane" level of protection.

The first case was analyzed because there are many homes with protection over windows and other glazed openings but no additional protection over solid (non-glazed) entry doors or garage doors. In addition, the first case also corresponds to FBC Section 1609.1.4, which only requires opening protection over glazed openings (except in Miami-Dade and Broward Counties). We did not analyze the case when some of the windows and doors are protected and other windows and doors are not protected. For the second case, all openings are protected, including all non-glazed doors.

The level of protection (None, OSB, Plywood, Ordinary, Basic, or Hurricane) is determined separately from the extent of protection. The level of protection is the lowest level of protection present among either all glazed openings or all openings. See A.1.1.8 and A.1.2.8 for further details.

A.1.2.4. Gable End Bracing

The end walls of gable roofs extend vertically to the sloping roof line. These gable end walls, if not properly built, have been noted to fail outward due to the negative suctions on the wall.

There are two ways that gable end walls fail. The first mode of failure occurs when the roof deck fails on the gable end and the gable end truss becomes unstable due to lack lateral restraint at the top of the end truss or rafter. The gable end wall therefore will generally collapse. This failure mode can be prevented by properly securing the roof deck at the gable end with higher density nailing patterns. Once the roof deck is lost, the building experiences high losses because of the vast amounts of rain water that enter the structure. Hence, the gable end failure in this case is not the primary cause of the high loss, but a result of the failure of the roof deck. Improved roof deck nailing and/or bracing of the top chord of the gable end can prevent this type of failure. However, if the roof deck fails the building will still have high losses regardless of whether the gable end wall fails or not.

Another failure mode for gable end walls includes failure at the bottom chord of the truss. There are many ways to properly brace a gable end wall, and this is further complicated by the wide variety of custom engineered solutions available.

There are four general types of gable end wall construction that are commonly seen in the field. These are masonry walls, balloon framed walls, truss walls, and platform or standard frame walls.

- ***Braced Gable Ends.*** Masonry walls and balloon framed walls continuous up to the roof diaphragm are considered braced. All truss and platform framed gable walls 4 feet or more in height require bracing systems meeting the prescriptive requirements of the FBC 2006 or the Florida Residential Construction Mitigation Program's "Gable End Retrofit Guide" (http://www.floridadisaster.org/mitigation/rcmp/HRG/content/structural/gable_ end_guide.asp).

Bracing of gable end walls is relatively easy provided there is attic access. Figure A-10 shows an example of cross bracing from the gable end to the second truss.



Figure A-10. Gable End Bracing Secured with Metal Connections

The HURLOSS analysis for gable end failures has focused on bottom chord failures for improperly braced gable ends. No analysis was performed for top chord failures, as experiments would be required to provide supporting data to model this failure mode properly.

A.1.2.5. Foundation Restraint

Foundation failures from hurricane wind forces alone are very rare. Typically, foundation failures associated with hurricanes occur when the surge from the water damages the foundation and structure.

Typical foundations include the following, as shown in Figure A-11:

- Crawl space (Stem Wall)
- Basement
- Slab on Grade with Stem Wall
- Monolithic slab
- Piles
- Piers/Posts

A crawl space is a perimeter foundation that creates an enclosed under-floor space that is not habitable. The perimeter foundation is typically a continuous footing with a stem wall that is attached to the wall/flooring structure of the building. The interior area in a crawl space may or may not extend below grade. Alternatively, a basement foundation is a wall foundation that extends below grade and encloses an area that may be used for living space or storage.

A slab on grade foundation with a stem wall is a concrete floor that is supported directly by the soil, and an independent stem wall that supports the weight of the building. A monolithic slab is a concrete floor that has an integrated footing that supports the weight of the building.

Pile foundations are necessary when the weight of the building must be transmitted to a deeper soil layer that is more stable, or when the structure must be elevated above required flood elevations. Pier or Post foundations are sometimes an economical alternative to stem wall perimeter foundations. These foundations may or may not have bracing between posts/piers depending on the height of the post/pier compared to its width. There may also be bracing or in-filled masonry walls between the posts and piers to resist lateral loads. Note that pile foundations are typically much deeper than post/pier foundations.

Inspections of foundation attachments are not practical for common slab-on-grade construction. Inspections of stem wall foundations require access through a crawl space. Because of these issues and the fact that foundation failures are very rare for hurricane winds (and, if they do occur, the house is usually significantly damaged from other failures), we have classified foundations into:

- ***Restrained:*** Foundations are assumed to have sufficient horizontal and vertical restraining forces unless classified as unrestrained.
- ***Unrestrained.*** Houses or Group I Buildings that are supported at discrete points by piles, piers, posts, or blocks and such that the support system has obviously-inadequate connections and/or bracing at the foundation support points to resist the uplift and horizontal wind forces acting on the building.

Almost all site-built houses will qualify as restrained. Building codes and inspections of houses confirm that there is almost always an attachment mechanism that provides suitable uplift and lateral resistance, especially when the building weight is also considered. Houses or Group I buildings built directly on slabs or stem walls should be assumed to be restrained, unless there is clear visible evidence that the building has previously moved laterally from its original position and is at further risk of sliding or

overturning from hurricane wind loads. The unrestrained category is intended only for the most obvious situations, such as; (1) a building supported by stacked concrete blocks at discrete points (see Figure 1-12); (2) a building on piles or piers where there are 2 or more piles with missing or severely corroded fasteners; and (3) a building where the discrete supports are leaning, inclined or have slipped from their original intended orientation. These examples illustrate that the use of "unrestrained" should be for only readily discernable cases where the building could be uplifted from the foundation and or severe sliding and overturning of the entire building is possible.

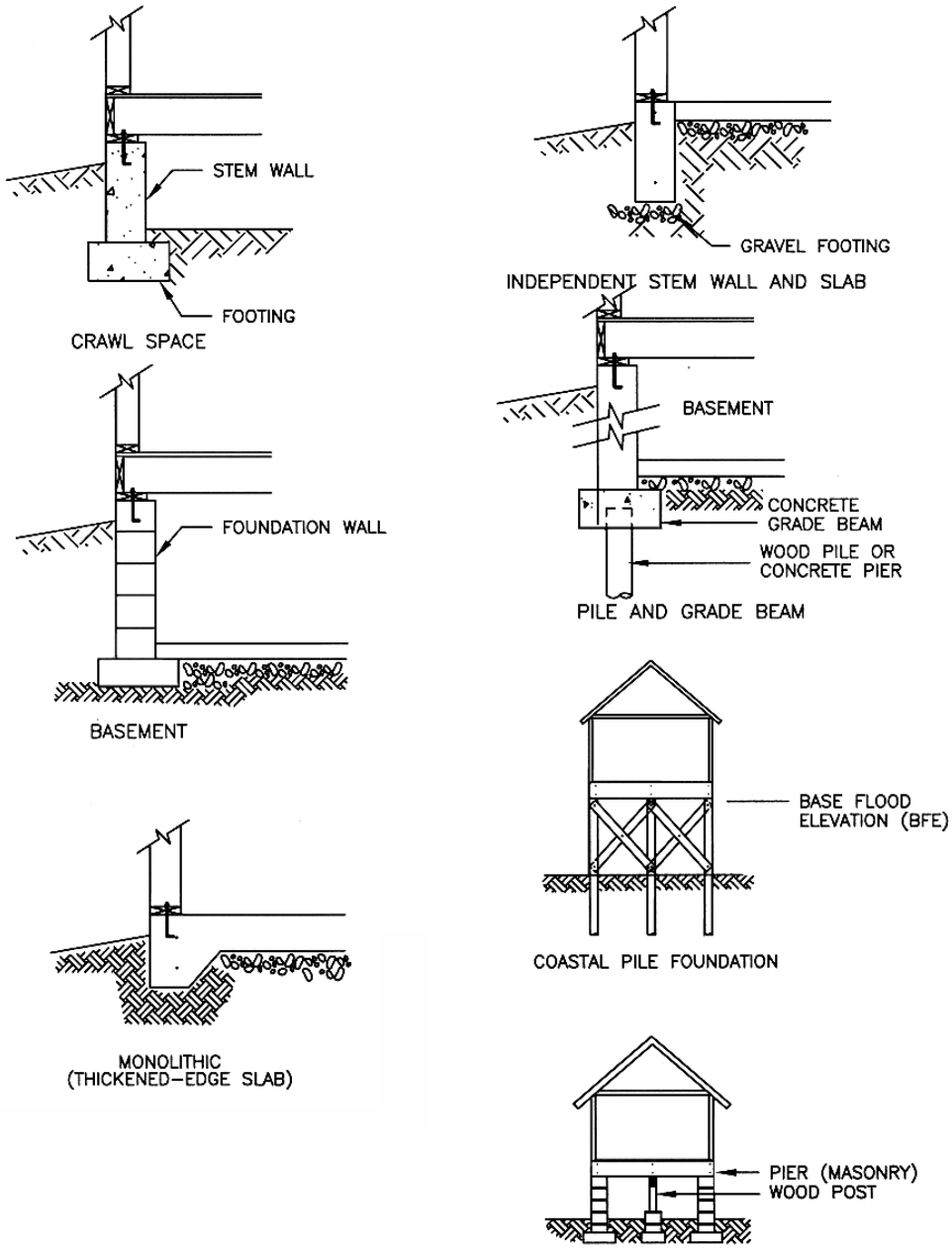


Figure A-11. Typical Foundation Types in Residential Construction (adapted from Residential Structural Design Guide, 2000 Edition, US. Dept of Housing and Urban Development, March 2000)

In computing the unrestrained foundation secondary factors, our modeling of unrestrained foundations included the case of a foundation provided only by discrete supports, with only support friction resisting the lateral wind loads. The wind uplift forces were resisted by the weight of the building. The modeling treated two failure modes – sliding of the building off the foundation and overturning of the entire building. The secondary factors for unrestrained foundations in Table 4-15 were developed in 2002 and have not been reanalyzed in this study.

A.1.2.6. Reinforced Concrete Roof Deck

Although not very common in residential construction in Florida, there are homes constructed with reinforced concrete roof decks. When these building are equipped with wind-borne debris impact resistant opening protection, they are extremely resistant to building failures. Damage to the building will largely consist of damage to the wall finish and roof covering (if any). The hurricane loss costs are therefore reduced dramatically.

- ***Concrete Roof Decks.*** At least 90% of the main roof deck is reinforced concrete designed and constructed in accordance with the provisions of ACI (American Concrete Institute) 318, including integral construction with a reinforced masonry or reinforced concrete wall system.

The roof covering on concrete roof decks for SF homes is either classified as "tile" or "other." Note that there are no Group I type buildings with reinforced concrete roof decks. Such buildings must be classified as Group II buildings.

A.1.2.7. Enhanced Roof Deck

Roof deck strengths beyond Roof Deck Attachment Level C (see Section A.1.1.7) can be achieved with thicker plywood and stronger fasteners. The requirements for the "enhanced" roof deck secondary factor are as follows:

- ***Enhanced Roof Deck.*** Plywood roof decks meeting the minimum requirements of Roof Deck Attachment Level C are considered "enhanced" if the deck is constructed with 5/8 inch thick (or thicker) plywood and the fasteners are either 8d ring shank nails or 2½ inch screws.

Enhanced roof decks can be determined through visual inspection.

A.1.2.8. Shutter Interpolation between None and Hurricane

There are three secondary levels of opening protection that fall between the two primary levels of None and Hurricane. These intermediate levels of protection are defined below.

- ***Basic.*** The Basic level of protection corresponds to 32% of the impact energy resistance of the Miami-Dade standards (112 ft lb of energy). This corresponds to Missile Level B (4.5 lb 2″ × 4″ missile at 40 ft/sec) in ASTM E 1996.
- ***Plywood or OSB Wood Structural Panels.*** Wood structural panels with a minimum thickness of 7/16" and a maximum span of 8 feet meeting the requirements of Section 1609.1.4 of the 2006 FBC. Wood structural panels must be precut and predrilled and are only permitted on one- and two-story buildings. All required hardware must be provided with anchors permanently installed on the building in accordance with Table 1609.1.4. Plywood panels have been found to perform better than Oriented Strand Board (OSB) panels. Separate

relativity interpolation factors are provided in Table 4-15 for Plywood and OSB wood structural panels.

- ***Ordinary.*** There are many untested opening protection products that have been installed in Florida both prior to and after the development of the impact/pressure cycling standards. In general, these products provide some protection for pressure and missile impact, but there is no practical way to quantify all the possible variations in debris impact and pressure cycling resistance. The Citizens class plan has an "Ordinary" protection level based on ASCE 7-88 wind pressure design that provides an intermediate level of protection between the Miami-Dade standard and no opening protection. We include an "Ordinary" shutter in Table 4-15, which is similar to the OSB level of protection. Ordinary shutters include certain steel, aluminum, and polycarbonate products that are properly installed but do not meet the current impact/pressure-cycling test standards. Many of these products may have been installed prior to the standardized requirements for wind-borne debris impact and hurricane pressure cycle loads. We also recommend that the "Ordinary" shutter designation includes shutters of any style and material that meets the ASCE 7-88 requirement for wind pressure resistance.[3] We map the Ordinary designation to the OSB shutter protection since this is the minimal level of opening protection recognized in this study. These products will provide protection for shingle and other light weight debris as well as provide some rain-screen protection of the openings to reduce the effects of wind-driven rain.

The applicable level of protection is the weakest level of protection present on the building when considering either All Glazed Openings or All Openings (see Section A.1.2.3).

A.1.2.9. Vinyl Siding

Vinyl siding is an exterior wall covering that has been observed to be more vulnerable to failure in windstorms than other types of siding. We apply an engineering judgment factor of 1.02 for houses with vinyl siding wall covers.

- ***Vinyl Siding.*** A shaped material, made principally from rigid polyvinyl chloride (PVC) that is used as an exterior wall covering on at least one-third of the exterior wall area of the building.

A.1.2.10. Window, Door, and Skylight Water Leak Potential

Windows, doors, and skylights are highly vulnerable to water leaks in hurricanes. The pressure differential across these openings tends to force water into cracks that exist between the moving and stationary parts of the window or door. Water moves from the outside of the building to the inside of the building or into the wall cavity. Part of this problem is due to the fact that the building codes only require leakage testing of components to 15% of the design pressure. Field observations also confirm that windows and doors leak in hurricanes. We used wind engineering judgment and calculations to develop the factors in Table 4-15.

- ***Window, Door, and Skylight Water Leak Potential***. The leakage factor in Table 4-15 is assumed to be linear in the number of openings (windows, doors, and skylights). Each window, door, garage door, or skylight unit counts as one opening except that sliding glass

[3] The "Ordinary" protection rating provides credits to policy holders with existing shutter devices that cannot be verified under the more stringent Hurricane or Basic definitions. The Ordinary credit allows for policyholders to receive a credit for their devices that will provide some protection. ARA developed the concept of Ordinary shutters as part of a study for Citizens Property Insurance Corp in 2002. Ordinary was mapped to plywood opening protection in earlier studies. However, due to the fact that Ordinary shutters do not have minimal fastening requirements (whereas the fastening requirements for OSB/Plywood panels are specified in the FBC), we map Ordinary shutters to the weaker OSB type in this study.

doors are counted as four openings. If the windows are shuttered with ***non-porous shutters***, the effect of the shutters is to reduce the amount of water that reaches the opening because the shutter acts as a rain screen. Considering these effects, we reduced the leakage factors for shuttered openings. The leakage rates are expected to be less for casement and fixed windows, due to the fact that fixed windows have no moving parts and casement windows operate in such a way that they leak less when subjected to positive pressure on the windward side of the house. If both casement or fixed windows and other window types are present, the factor is the product of Factor "a" and Factor "b".

- ***Non-Porous Shutter.*** A shutter-type of opening-protection device that covers the entire opening and is not permeable. For example, non-porous shutters would include solid panel shutters and shutters without noticeable cracks or spacings between components that would allow subsequent leakage through the shutter. Leakage around the perimeter of the shutter is expected of all shutters, and, hence, porosity affects the portion of the shutter than covers the entire opening.
- ***Porous Shutter.*** All other types of shutters, including: (1) impact resistant glazing that isn't protected by non-porous shutters; and, (2) the case of "Opening Protection = None."

As noted in Table 4-15, the application of the water leak potential factor requires counting the openings, where sliding glass doors count as four openings.

A.1.2.11. Double Wrap Roof-to-Wall Connector

See Section A.1.1.6.

A.1.3. Additional Secondary Factors for Group I Multi-Family

There are two additional secondary factors for Group I MF buildings that are not used in the SF home relativities. The additional factors are related to features found on flat roof buildings.

A.1.3.1. Rooftop Equipment

Flat-roofed buildings often have air conditioning units and other equipment on the roof deck. The tie down connections and water proofing details around this equipment are important to the roof cover and roof deck performance. Equipment that is not tied down or inadequately-restrained poses the most significant risk.

- ***Adequately-Restrained Rooftop Equipment.*** Equipment and supports are fastened to the roof structure with connections designed to resist lateral loads and uplift loads in accordance with the 2006 revisions to the 2004 FBC. This may be accomplished by design or by Section 301.13.1, which outlines the anchorage requirements for roof top equipment. When verifying adequate restraint by visual inspection on pre-FBC buildings, equipment mounted on a frame and restrained by at least two metal straps with at least two screws or bolts at each end shall be deemed to be adequately restrained provided that the screws or bolts are or sufficient length and diameter to ensure a positive connection with the roof structure system.
- ***Inadequately-Restrained Rooftop Equipment.*** One or more items of rooftop equipment are not adequately restrained. Significant corrosion, missing fasteners, or broken straps shall be considered evidence of inadequate restraint.

A.1.3.2. Parapets

A parapet is a low wall projecting up from the edge of a roof. They are sometimes used to conceal roof top equipment. Flat-roofed buildings with parapets can experience lower uplift pressures than flat-roofed buildings without parapets.

- ***Parapet.*** A wall projecting up from the entire perimeter of a flat roof. The minimum height must be 6 feet to qualify for a reduction in loss relativity.
- ***No Parapet.*** All other flat roof buildings.

A.2. Group II or Group III Multi-Family

Group II Multi-Family (MF) buildings include all residential dwellings with 5 or more units with reinforced concrete or steel frame construction up to 60 feet in height. These buildings are typically one to five stories in height.

Group III Multi-Family (MF) buildings include all residential dwellings with 5 or more units taller than 60 feet. These buildings are typically six or more stories in height and typically have reinforced concrete or steel frame construction.

For Group II and Group III MF residential buildings the following ***building code eras*** are defined:

- ***FBC 2001.*** Group II or Group III buildings treated as being designed to the wind load provisions of the 2001 FBC. This era includes buildings permitted on or after March 1, 2002.
- ***SBC 1988 (Group II).*** Group II buildings treated as being designed to the wind load provisions of the 1988 SBC. This era includes buildings permitted between January 1, 1983 and February 28, 2002.
- ***ASCE 1988 (Group III).*** Group III buildings treated as being designed to the wind load provisions of the 1988 SBC, and Group III buildings treated as being designed to the wind load provisions of the 1988 edition of ASCE 7. This era includes buildings permitted between January 1, 1983 and February 28, 2002.
- ***SBC 1976.*** Group II or Group III buildings permitted before January 1, 1983.

A.2.1. Primary Factors

The primary factors for Group II and Group III MR residential buildings are defined in the following sub-sections.

A.2.1.1. Terrain

See Section A.1.1.1.

A.2.1.2. Roof Cover Strength

See Section A.1.1.4.

A.2.1.3. Secondary Water Resistance

See Section A.1.1.5.

A.2.1.4. Opening Protection – None vs. Hurricane

See Section A.1.1.8.

A.2.1.5. Roof Deck

For Group II and Group III buildings, the most common roof deck types are reinforced concrete roof decks or corrugated metal roof decks supported on rolled steel framing or open web steel joists. [4] Thus, for practical reasons, we consider only two basic roof deck types for Group II and Group III buildings in this study: concrete and metal. For classification purposes, the metal deck classification can be thought of as "not a reinforced concrete roof deck".

- ***Concrete Roof Decks.*** At least 90% of the main roof deck is reinforced concrete designed and constructed in accordance with the provisions of ACI (American Concrete Institute) 318 and properly connected to the rest of the structure.
- ***Metal Roof Decks.*** Any Group II or Group III building not classified as having a Concrete Roof Deck. Buildings in this group are modeled as having metal roof decks supported by open web steel joists.

A.2.2. Secondary Factors

The secondary factors for Group II and Group III MR residential buildings are defined in the following sub-sections.

A.2.2.1. Roof Top Equipment

See Section A.1.3.1.

A.2.2.2. Parapets

See Section A.1.3.2.

[4] Recall that MF residential buildings up to 60 feet in height with wood panel roof decks are classified as Group I buildings.

Appendix B. Observed and Modeled Windspeeds for 2004-5 Florida Hurricanes

This appendix contains the ARA hurricane windfield model windspeeds (peak gust windspeed in unobstructed open terrain) at the zip code level for Hurricanes Ivan, Jeanne, Frances, Charley, Dennis, Katrina, and Wilma. The windspeeds developed were used in the insurance data analysis discussed in Section 3. Significant effort was put forth into validating the modeled windspeeds through comparisons with full scale records of windspeeds, wind directions, and pressures measured both over water and on land. The following paragraphs present summaries of the windspeed for these hurricanes.

Hurricane Ivan: The observed windspeeds in Hurricane Ivan cover a region all the way from New Orleans to the west of the landfall point, through to Tallahassee, well to the east of the point of landfall. As indicated in Figure B-1, there is very good agreement between the maximum modeled and observed windspeeds. Each data point given in Figure B-1 represents the observed (x-axis) and modeled windspeed at an individual measurement location. The model and the observations indicate that the Pensacola area experienced peak gust windspeeds (in open unobstructed terrain) of about 110 mph, reducing to less than about 50 mph in the Tallahassee area. The good agreement between the modeled and observed windspeeds provides us with the confidence that the modeled peak gust windspeeds represent a reliable estimate of the actual maximum windspeeds experienced by the homes in Hurricane Ivan. Figure B-2 shows contours of the maximum modeled peak gust windspeeds as well as the locations of the anemometers for which the comparisons between modeled and observed windspeeds were performed.

Hurricane Jeanne: Figure B-3 presents a summary comparison plot of the observed and modeled peak gust windspeeds produced by Hurricane Jeanne in Florida. The observed windspeeds cover a region from Fort Lauderdale to the south of the landfall point, through to Jacksonville, to the north of the point of landfall, in addition to points on the west coast near Tampa, and inland around the Orlando area. As indicated in Figure B-3, there is good agreement between the modeled and observed windspeeds, with both the model and the observations indicating that the area just to the north of the landfall point experienced peak gust windspeeds (in open unobstructed terrain) of about 110 mph, reducing to about than 80-90 mph in the Orlando area, 70-80 mph in the Tampa area and about 70 mph in the Gainesville area. The good agreement between the modeled and observed windspeeds provides us with the confidence that the modeled peak gust windspeeds represent a reliable estimate of the actual maximum windspeeds experienced by the homes in most of the areas affected Hurricane Jeanne, although the model appears to overestimate windspeeds in the Fort Lauderdale area. Figure B-4 shows contours of the maximum modeled peak gust windspeeds as well as the locations of the anemometers for which the comparisons between modeled and observed windspeeds were performed.

Hurricane Frances: Figure B-5 presents a summary comparison plot of the observed and modeled peak gust windspeeds produced by Hurricane Frances in Florida. The observed windspeeds cover a region from Fort Lauderdale to the south of the landfall point, through to Jacksonville, to the north of the point of landfall, in addition to points on the west coast near Tampa, and inland around the Orlando area. As indicated in Figure B-5, there is fair agreement between the modeled and observed windspeeds, but it is not as good as in the case of Hurricanes Ivan and Jeanne. The model tends to underestimate windspeeds well to the north of the point of landfall, and overestimate windspeeds near the point of landfall.

The model results and observation indicate that the area just to the north of the landfall point experienced peak gust windspeeds (in open unobstructed terrain) of about 110 mph, reducing to about than 70-80 mph in the Orlando area, 60-70 mph in the Tampa about 70 mph in the Gainesville area. Windspeeds in the Daytona Beach through to Jacksonville ranged from about 80 mph at Daytona Beach, reducing to about 70 mph near Jacksonville. Windspeeds in this area of Florida are underestimated using

the wind model. Figure B-6 shows contours of the maximum modeled peak gust windspeeds as well as the locations of the anemometers for which the comparisons between modeled and observed windspeeds were performed.

Hurricane Charley: Figure B-7 presents a summary comparison plot of the observed and modeled peak gust windspeeds produced by Hurricane Charley in Florida. The observed windspeeds cover a region from the Punta Gorda-Port Charlotte regions though Orlando to the East coast of Florida. As indicated in Figure B-7, the agreement between the modeled and observed windspeeds is very good.

The model results indicate that the maximum peak gust windspeeds on land at the point of landfall were about 140 mph to 150 mph. Peak gust windspeeds in excess of 100 mph were experienced at locations as far inland as Orlando. Figure B-8 shows contours of the maximum modeled peak gust windspeeds as well as the locations of the anemometers for which the comparisons between modeled and observed windspeeds were performed.

Hurricane Dennis: Figure B-9 presents a summary comparison of the observed and modeled peak gust wind speeds for Hurricane Dennis. The model results indicate that the maximum peak gust wind speeds on land at the point of landfall were about 110 mph. Figure B-10 shows contours of the maximum modeled peak gust wind speeds as well as the locations of the anemometers for which the comparisons between modeled and observed wind speeds were performed.

Hurricane Katrina: Figure B-11 presents a summary comparison of the observed and modeled peak gust wind speeds for Hurricane Katrina in South Florida. The model results indicate that the maximum peak gust wind speeds on land at the point of landfall were a little more than 80 mph, and these high winds affected only a small area in Broward County. Figure B-12 shows contours of the maximum modeled peak gust wind speeds as well as the locations of the anemometers for which the comparisons between modeled and observed wind speeds were performed.

Hurricane Wilma: Figure B-13 presents a summary comparison of the observed and modeled peak gust wind speeds for Hurricane Wilma in South Florida. The model results indicate that the maximum peak gust wind speeds on land were about 120 mph. Figure B-14 shows contours of the maximum modeled peak gust wind speeds as well as the locations of the anemometers for which the comparisons between modeled and observed wind speeds were performed. The contours given in Figure B-14 indicate that the strong winds occurred on both the west and east coasts of Florida, as the hurricane weakened little as it progressed across South Florida. It is also noteworthy that the highest measured wind occurred on the left hand side of the storm.

ASOS	Description	Peak Gust Speed (mph)	
		Obs	Model
42003	*Data Buoy*	85	86
42007	*Data Buoy*	96	96
BURL1	*Southwest Pass, LA C-MAN Station*	91	89
DPIA1	*Dauphin Island C-MAN*	102	114
GDIL1	*Grand Isle C-MAN*	69	66
SGOF1	*Tyndall AFB C-MAN Station*	65	57
KBHM	Birmingham Int Airport, AL ASOS		56
KDHN	Dothan, AL ASOS	57	54
KDTS	Destin, FL ASOS		83
KGPT	Gulfport, MS ASOS		69
KMGM	Montgomery Regional Airport, AL ASOS	67	68
KBIX	Biloxi-Keesler AFB	73	76
KNEW	New Orleans Lakefront Airport	57	52
KMSY	New Orleans International Airport	48	46
KTLH	Tallahassee Regional Airport	54	45
KMOB	Mobile, AL ASOS	84	92
KMXF	Maxwell AFB, AL ASOS	68	67
KPFN	Panama City Airport ASOS	68	62
KNPA	Pensacola Naval Station ASOS	110	109
KPNS	Pensacola Regional Airport ASOS		105
KVPS	Eglin AFB ASOS	96	82
T1	FCMP Tower T1	107	105
T2	FCMP Tower T2	91	103
WEMITE 1	Texas Tech University Tower	104	108
DOW3	Doppler on Wheels Anemometer	109	108

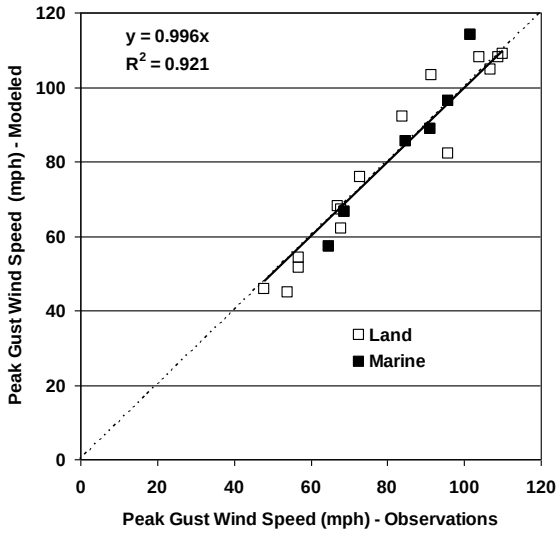


Figure B-1. Comparisons of Modeled and Observed Peak Gust Windspeeds for Hurricane Ivan.

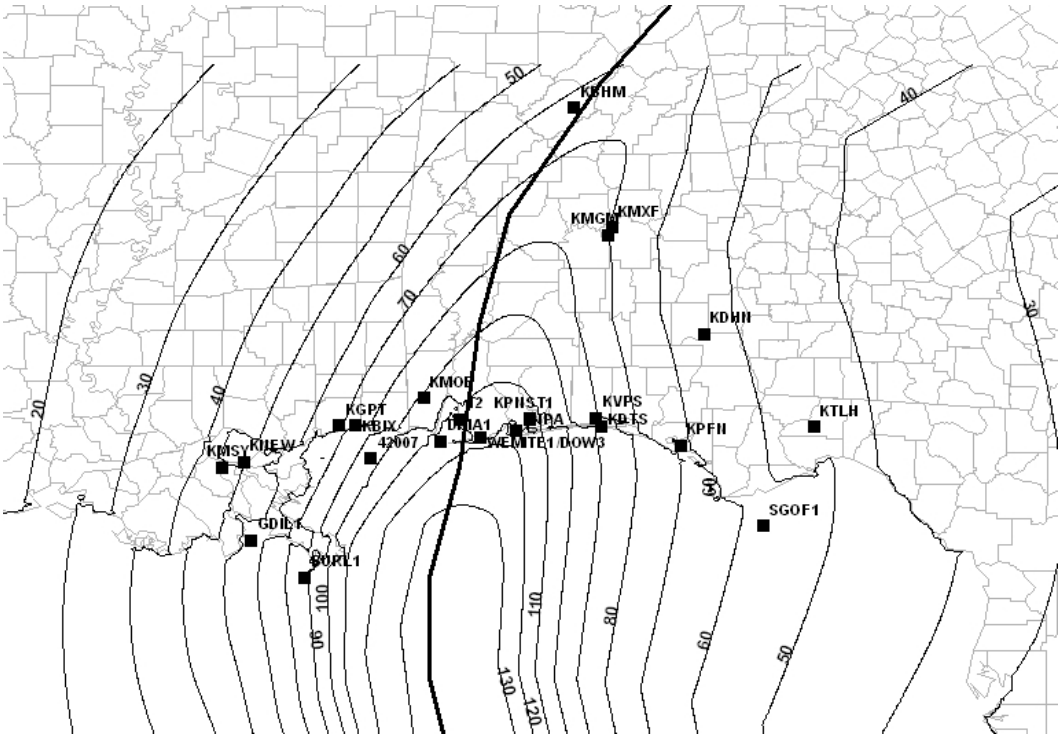


Figure B-2. Contours of maximum peak gust windspeed (mph) at a height of 10m above ground produced by the windfield model for Hurricane Ivan. Contours for over land windspeeds are representative of the peak gust windspeeds in open terrain. Contours for over water windspeeds are representative of peak gust windspeeds in marine conditions. The discontinuity near the coast is caused by the reduction in windspeed as the wind moves from the ocean to land.

ASOS	Description	Peak Gust Speed (mph)	
		Observed	Modeled
KDAB	Daytona Beach ASOS	70	60
KFLL	Fort Lauderdale ASOS	58	65
KFPR	Fort Pierce ASOS	105	104
KGNV	Gainesville ASOS	69	66
KJAX	Jacksonville ASOS	61	50
KLEE	Leesburg ASOS	77	73
KMCO	Orlando International Airport ASOS	83	82
KMLB	Melbourne ASOS		95
KPBI	Palm Beach Airport ASOS		91
KSFB	Orlando-Sanford International Airport ASOS	75	70
KTPA	Tampa International Airport ASOS	63	66
KVDF	Tampa Vandenburg ASOS	81	71
LKWF1	Lake Worth C-MAN Station	93	98
T0	FCMP Tower T0	88	88
T1	FCMP Tower T1	103	103
T2	FCMP Tower T2	71	74
T3	FCMP Tower T3	106	106
T3	FCMP Tower T3 - Gainsville	69	65
SAUF1	St. Augustine C-MAN Station	73	60
KMIA	Miami International Airport ASOS	43	55
KSGJ	St. Augustine Airport ASOS	63	54
KTLH	Tallahassee Regional Airport ASOS	55	40

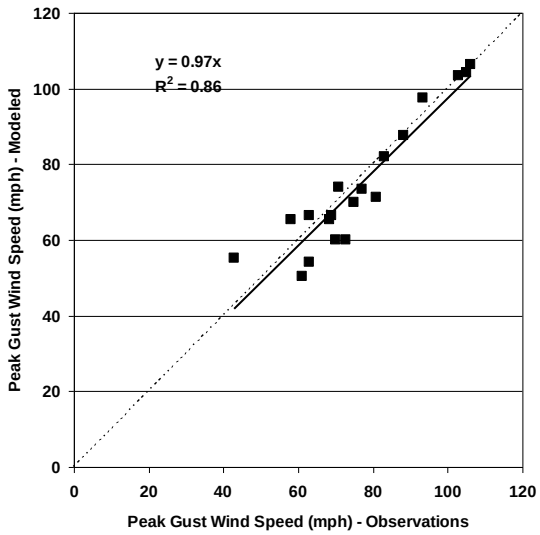


Figure B-3. Comparisons of Modeled and Observed Peak Gust Windspeeds for Hurricane Jeanne.

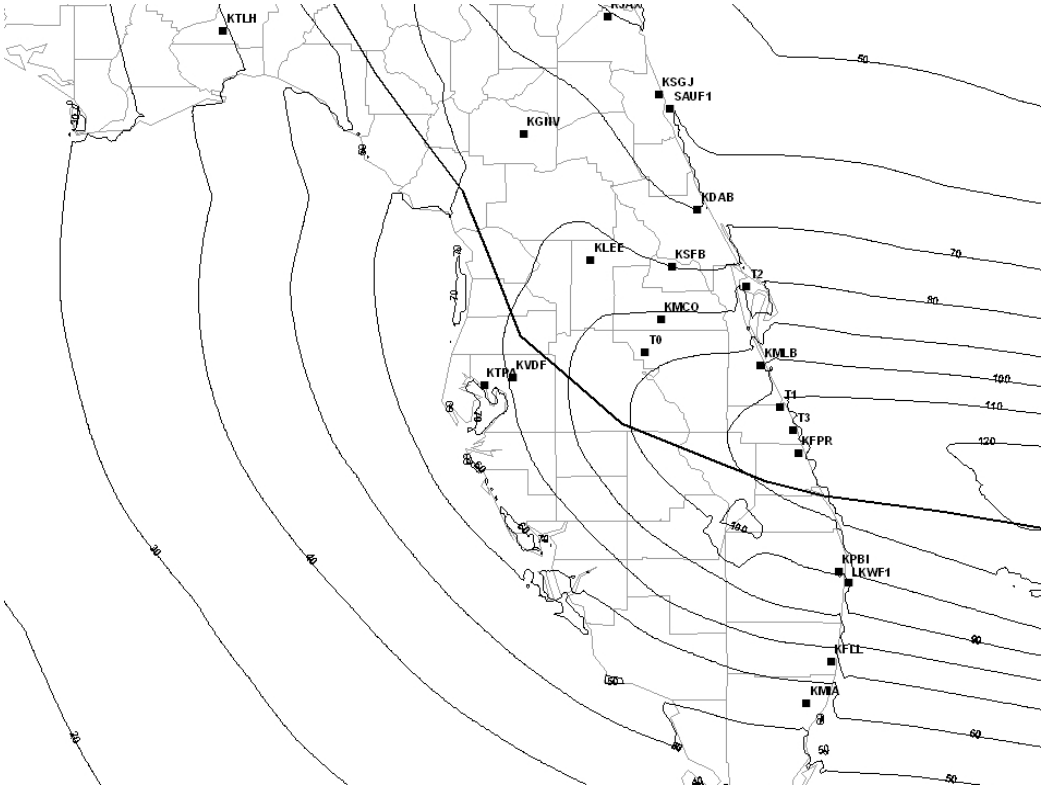


Figure B-4. Contours of maximum peak gust windspeed (mph) at a height of 10m above ground produced by the windfield model for Hurricane Jeanne. Contours for over land windspeeds are representative of the peak gust windspeeds in open terrain. Contours for over water windspeeds are representative of peak gust windspeeds in marine conditions. The discontinuity near the coast is caused by the reduction in windspeed as the wind moves from the ocean to land.

ASOS	Description	Peak Gust Speed (mph)	
		Observed	Modeled
KDAB	Daytona Beach ASOS	84	60
KFLL	Fort Lauderdale ASOS	62	74
KGIF	Fort Pierce ASOS		78
KJAX	Jacksonville Airport ASOS	69	46
KGNV	Gainesville ASOS	71	57
KLEE	Leesburg ASOS	71	71
KMCO	Orlando International Airport ASOS	71	78
KPBI	Palm Beach Airport ASOS	89	95
KSPG	St Petersburg	63	63
KTPA	Tampa International Airport ASOS	59	66
LKWF1	Lake Worth C-MAN Station		103
T0	FCMP Tower T0	90	101
T1	FCMP Tower T1	73	86
T2	FCMP Tower T2	88	103
T3	FCMP Tower T3	111	103
SAUF1	St. Augustine C-MAN Station	79	55

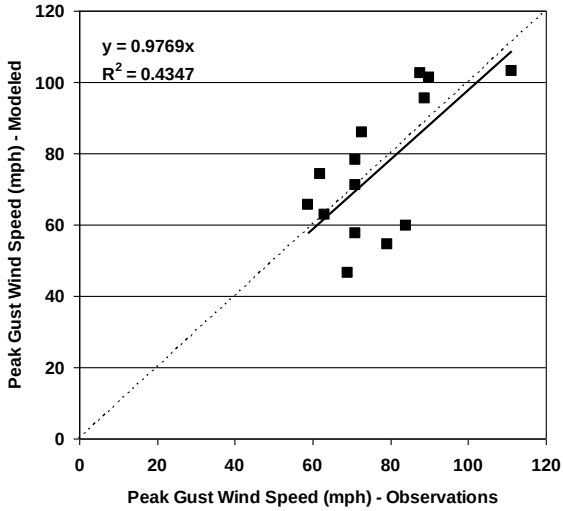


Figure B-5. Comparisons of Modeled and Observed Peak Gust Windspeeds for Hurricane Frances.

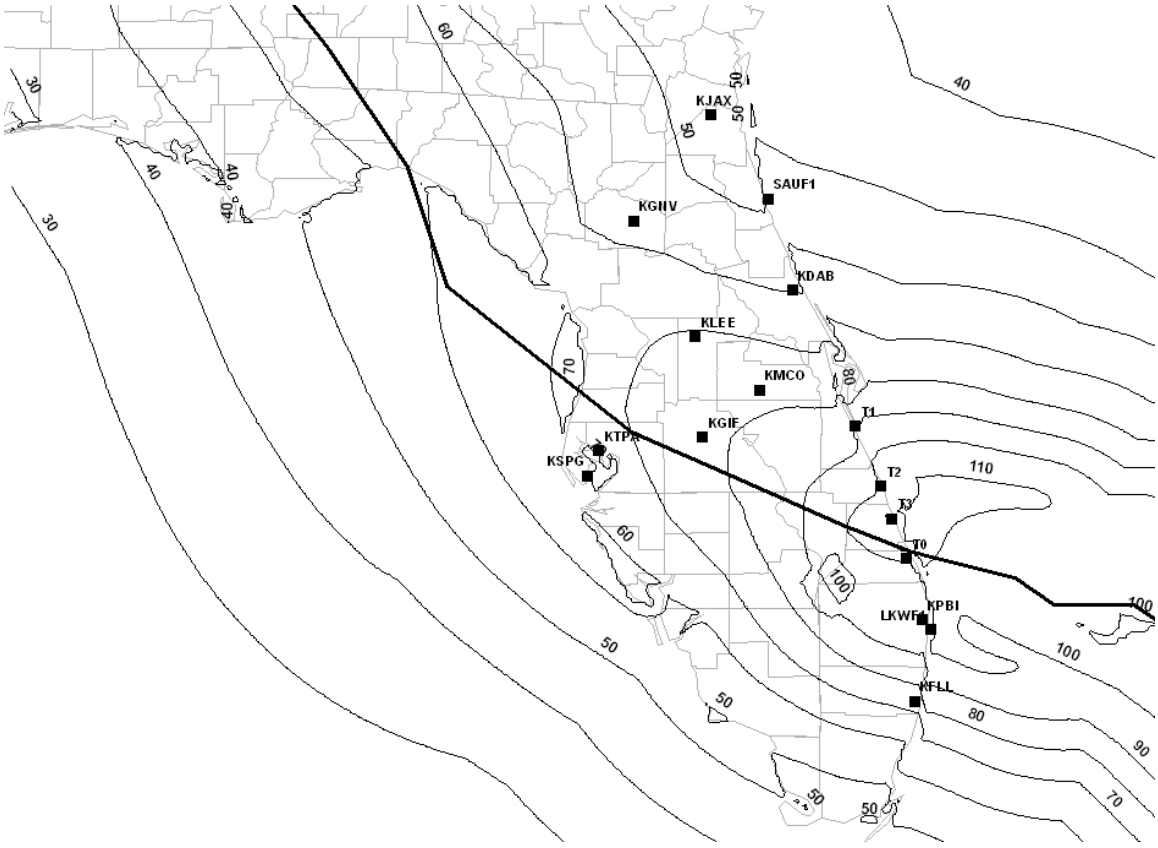


Figure B-6. Contours of maximum peak gust windspeed (mph) at a height of 10m above ground produced by the windfield model for Hurricane Frances. Contours for over land windspeeds are representative of the peak gust windspeeds in open terrain. Contours for over water windspeeds are representative of peak gust windspeeds in marine conditions. The discontinuity near the coast is caused by the reduction in windspeed as the wind moves from the ocean to land.

ASOS	Description	Peak Gust Speed (mph)	
		Obs	Model
KFMY	Fort Myers International Airport	85	80
KMCO	Orlando International Airport	107	109
KSFB	Orlando Sanford International Airport	94	91
KORL	Orlando Executive International Airport	87	97
KMIA	Miami International Airport	41	34
KMLB	Melbourne Regional Airport	49	53
KPBI	Palm Beach International Airport	41	37
KRSW	SouthWest Florida International Airport	81	69
FCMP T0	FCMP Tower T0	54	59
FCMP T1	FCMP Tower T1	76	82
FCMP T2	FCMP Tower T2	49	45
FCMP T3	FCMP Tower T3	39	43
SAUF1	St. Augustine C-MAN Station	71	65
KOMN	Ormond Beach Municipal Airport		80
KPGD	Charlotte County Airport		141

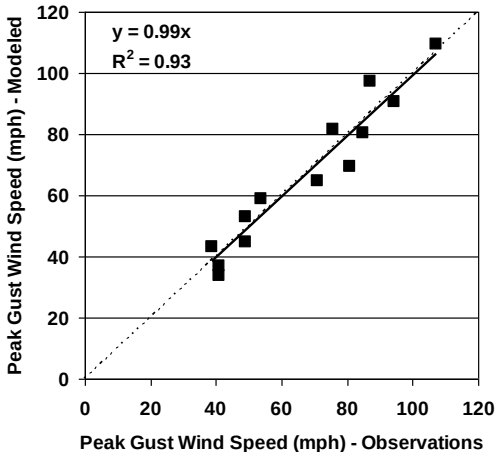


Figure B-7. Comparisons of Modeled and Observed Peak Gust Windspeeds for Hurricane Charley.

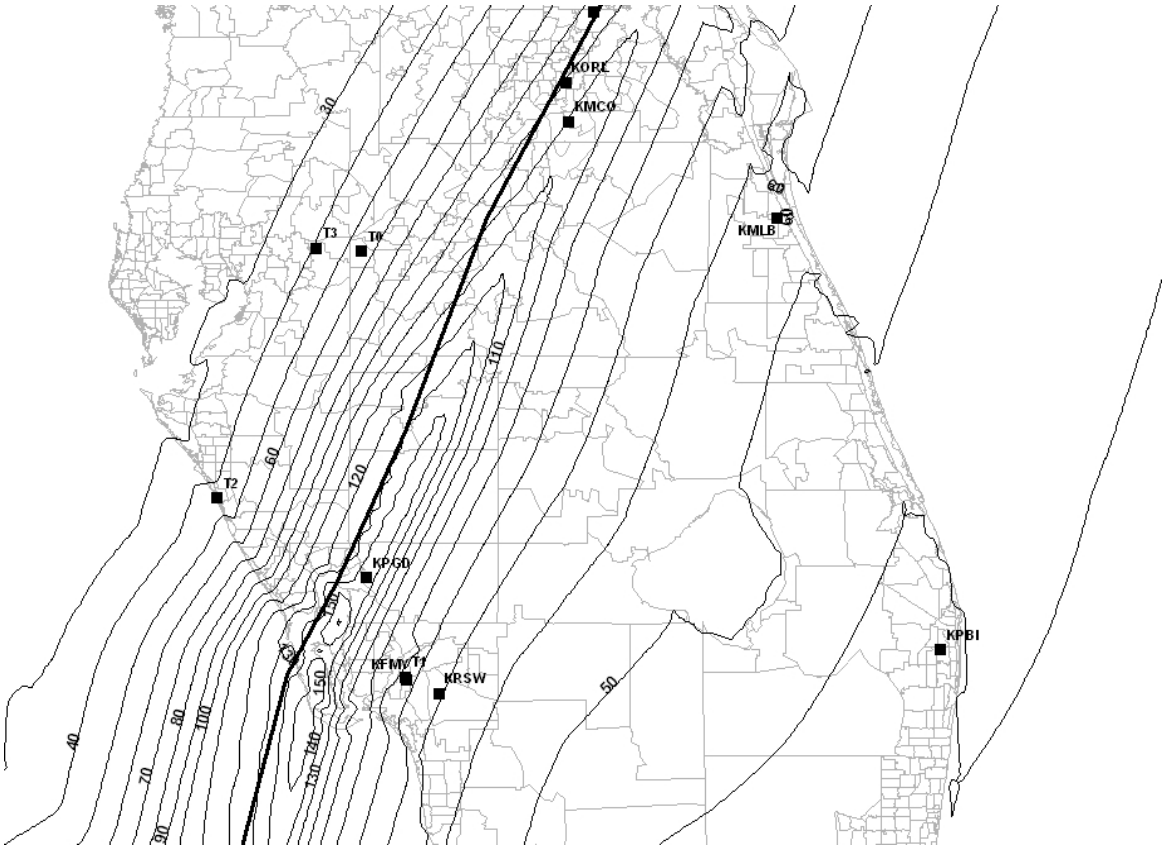


Figure B-8. Contours of maximum peak gust windspeed (mph) at a height of 10m above ground produced by the windfield model for Hurricane Charley. Contours for over land windspeeds are representative of the peak gust windspeeds in open terrain. Contours for over water windspeeds are representative of peak gust windspeeds in marine conditions. The discontinuity near the coast is caused by the reduction in windspeed as the wind moves from the ocean to land.

Station	Description	Peak Gust Wind Speed (mph)	
		Observed	Modeled
KPFN	Panama City Airport	57	56
KDTS	Destin-Fort Walton Beach Airport	76	84
KMOB	Mobile Airport	50	35
KNPA	Pensacola Naval Air Station Anemometer	62	74
T3	FCMP Tower	82	84
T2	FCMP Tower	105	87
T0	FCMP Tower	112	114
KVPS	Eglin Air Force Base Anemometer	85	83
KTCL	Tuscaloosa Regional Airport	47	36
42003	Data Buoy	57	48

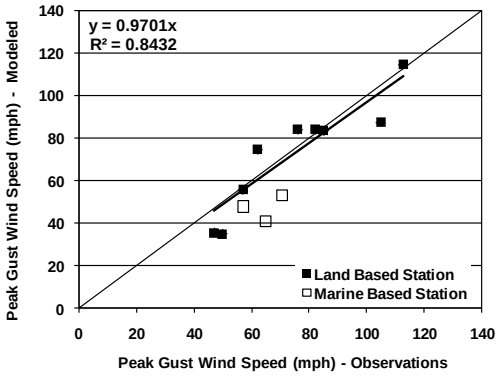


Figure B-9. Comparisons of Modeled and Observed Peak Gust Wind Speeds for Hurricane Dennis.

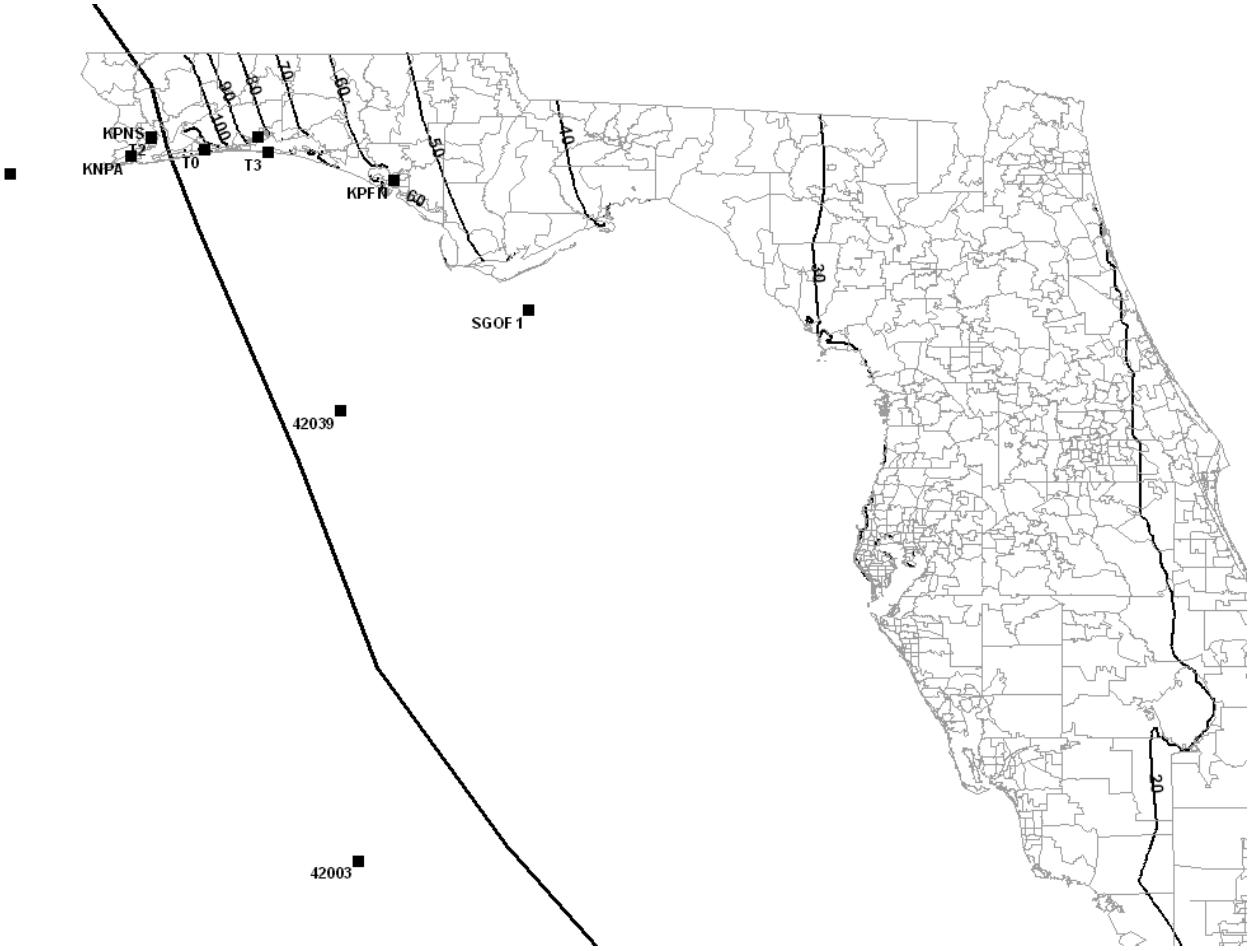


Figure B-10. Contours of maximum peak gust wind speed (mph) at a height of 10m above ground produced by the wind field model for Hurricane Dennis. Windspeeds are representative of the peak gust wind speeds in open terrain.

Station	Description	Peak gust Wind Speed (mph)	
		Observed	Modeled
KFLL	Fort Lauderdale Airport	84	78
KMIA	Miami Airport	81	77
MLRF	C-Man Station	76	64
FWFY1	C-Man Station	71	77
LONF1	C-Man Station	73	64
KPBI1	Palm Beach Airport	48	47
SMKF1	C-Man Station	70	64
KOPF	Opa Locka Airport, Miami	70	78
KFXE	Fort Lauderdale Executive Airport	68	80
KEYW	Key West International Airport	76	84

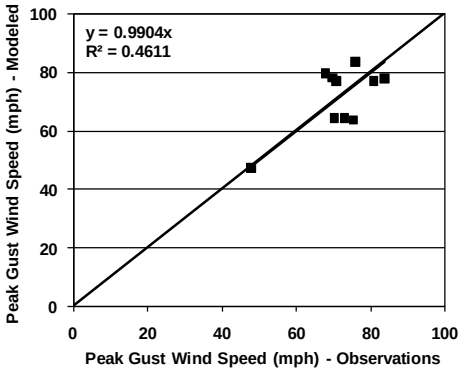


Figure B-11. Comparisons of Modeled and Observed Peak Gust Wind Speeds for Hurricane Katrina in South Florida.

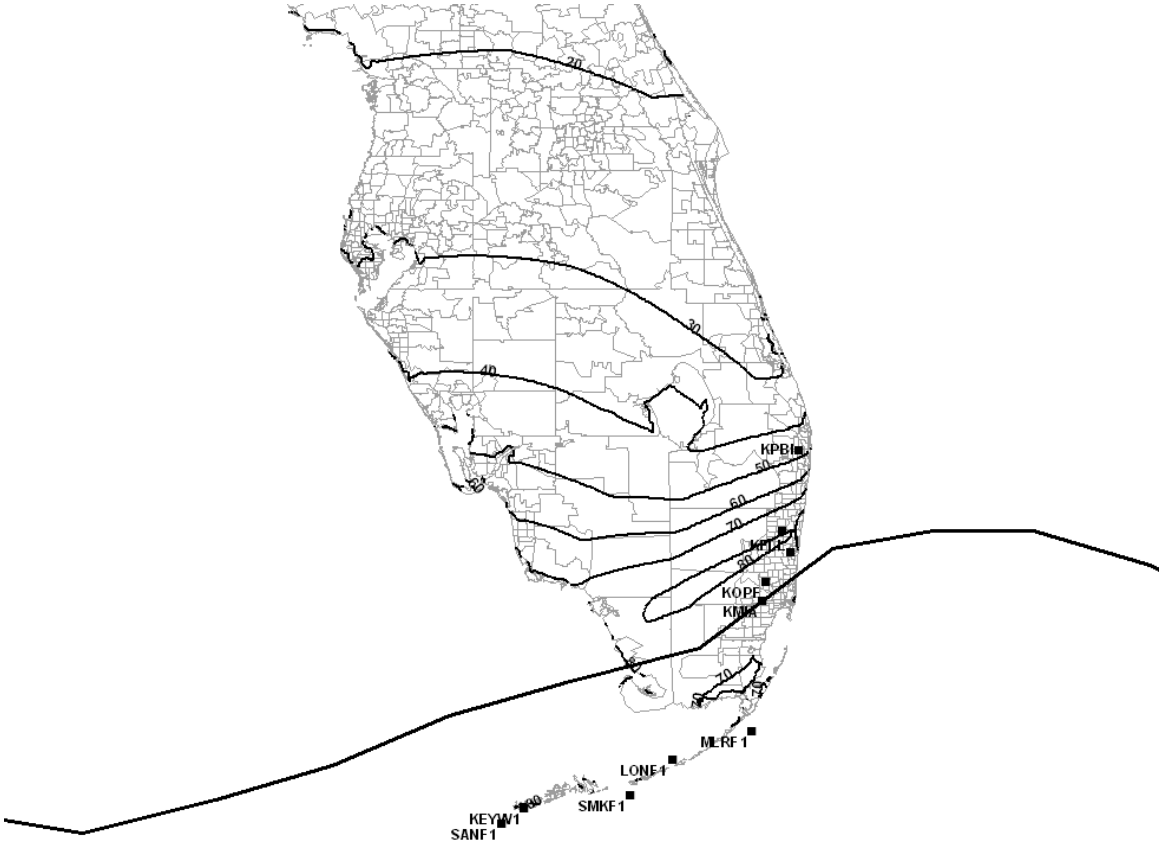


Figure B-12. Contours of maximum peak gust wind speed (mph) at a height of 10m above ground produced by the wind field model for Hurricane Katrina. Windspeeds are representative of the peak gust wind speeds in open terrain.

Station	Description	Peak Gust Wind Speed (mph)	
		Observed	Modeled
KMLB	Melbourne International Airport	65	46
KFMY	Fort Myers Airport	81	69
KFLL	Fort Lauderdale Airport	106	113
KPBI	Palm Beach Airport	108	115
KMIA	Miami Airport	99	109
KFPR	St. Lucie County Airport	87	76
T0	FCMP Tower	106	111
T1	FCMP Tower	105	122
T3	FCMP Tower	106	109
T2	FCMP Tower	117	120
FWFY1	Data Buoy	108	108
S140W	SFWMD Anemometer	108	113
LXWS	SFWMD Anemometer	113	118
LZ40	SFWMD Anemometer	109	115
S7WX	SFWMD Anemometer	115	114
STA5WX	SFWMD Anemometer	101	102
S331W	SFWMD Anemometer	113	108
BELLW	SFWMD Anemometer	111	101
L006	SFWMD Anemometer	112	123
L001	SFWMD Anemometer	107	87
SGGEWX	SFWMD Anemometer	107	119
ACRAWX	SFWMD Anemometer	124	110
VAKF1	C-MAN Station	99	113

SFWMD - South Florida Water Management District

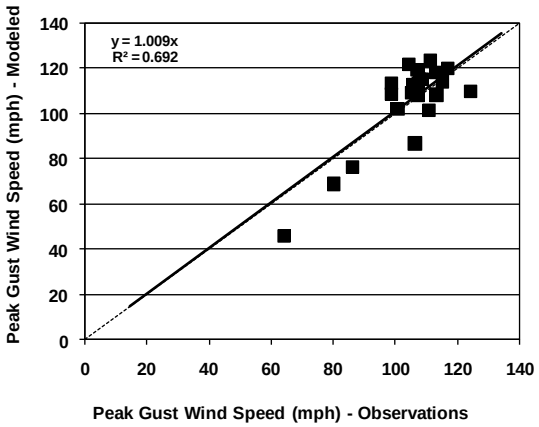


Figure B-13. Comparisons of Modeled and Observed Peak Gust Wind Speeds for Hurricane Wilma in South Florida.

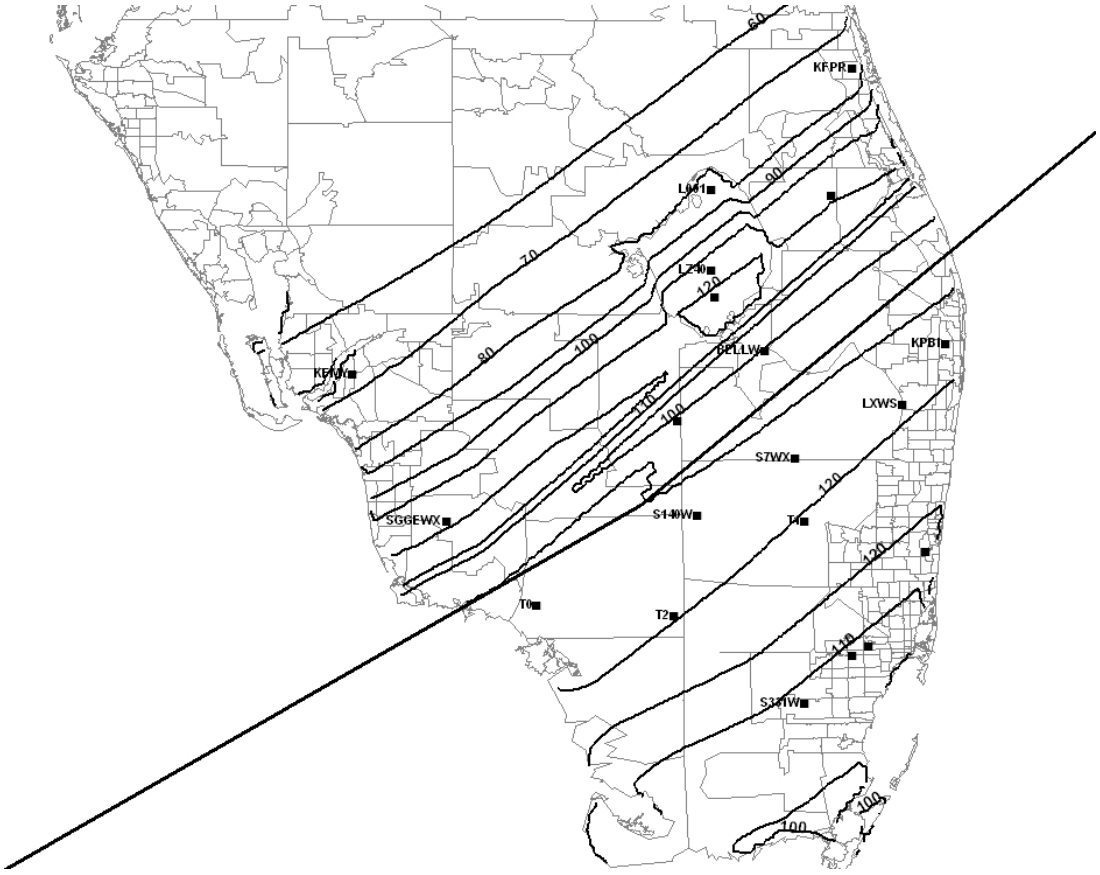


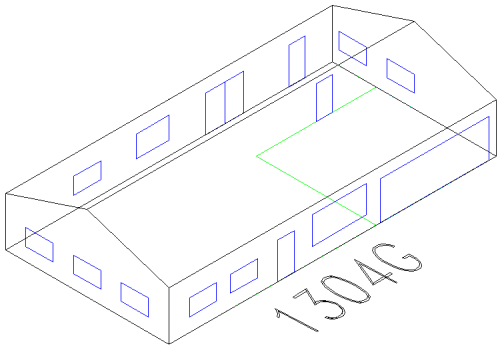
Figure B-14. Contours of maximum peak gust wind speed (mph) at a height of 10m above ground produced by the wind field model for Hurricane Wilma. Windspeeds are representative of the peak gust wind speeds in open terrain.

Appendix C. CAD Views of Model Buildings

This appendix includes CAD views of 44 model buildings in Table 2-6. The CAD model number adjacent to each figure corresponds to the "Building" column in the following table, which is a shortened version of Table 2-6. The color bands in Table C-1 represent single-family and multi-family Groups I, II, and III.

Table C-1. Summary Data for Modeled Buildings

Model Index No.	Builiding Group	Building Model	Roof Geometry	Roof Slope	No. of Stories	SF Garage	SF Porch	SF Skylight	Wall Area % Fens	Wall Area % Glazing	Total Sq Ft	Livable Sq Ft	Notes
1	SF	1304g	Gable	4:12	1	Yes	No	No	26	14	1,800	1,316	Simple model. This is model 0013 used in the 2002 studies
2	SF	1304h	Hip	4:12	1	Yes	No	No	26	15	1,800	1,316	Simple model. This is model 0013 used in the 2002 studies
3	SF	1307g	Gable	7:12	1	Yes	No	No	22	13	1,800	1,316	Simple model. This is model 0013 used in the 2002 studies
4	SF	1307h	Hip	7:12	1	Yes	No	No	26	15	1,800	1,316	Simple model. This is model 0013 used in the 2002 studies
5	SF	2304g	Gable	4:12	2	Yes	No	No	16	11	3,600	3,116	Simple 2 story model; not used in final production runs.
6	SF	2304h	Hip	4:12	2	Yes	No	No	17	12	3,600	3,116	Simple 2 story model; not used in final production runs.
7	SF	2307g	Gable	7:12	2	Yes	No	No	16	11	3,600	3,116	Simple 2 story model; not used in final production runs.
8	SF	2307h	Hip	7:12	2	Yes	No	No	17	12	3,600	3,116	Simple 2 story model; not used in final production runs.
9	SF	2204G	Gable	4:12	2	Yes	No	No	17	10	3,000	2,516	Simple 2 story model, used in previous studies.
10	SF	2204H	Hip	4:12	2	Yes	No	No	18	11	3,000	2,516	Simple 2 story model, used in previous studies.
11	SF	2207G	Gable	7:12	2	Yes	No	No	16	10	3,000	2,516	Simple 2 story model, used in previous studies.
12	SF	2207H	Hip	7:12	2	Yes	No	No	18	11	3,000	2,516	Simple 2 story model, used in previous studies.
13	SF	A103g	Gable	6:12	1	Yes	Yes	No	20	12	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
14	SF	A143g	Gable	4:12	1	Yes	Yes	No	18	11	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
15	SF	A143h	Hip	4:12	1	Yes	Yes	No	20	12	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
16	SF	A173g	Gable	7:12	1	Yes	Yes	No	16	10	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
17	SF	A173h	Hip	7:12	1	Yes	Yes	No	20	12	2,657	1,986	Actual Florida home w/ porch; not analyzed in study
18	SF	A144g	Gable	4:12	1	Yes	No	No	18	11	2,467	1,986	Actual Florida home design; A143g without porch;
19	SF	A144h	Hip	4:12	1	Yes	No	No	20	12	2,467	1,986	A143h without porch
20	SF	A174g	Gable	7:12	1	Yes	No	No	16	10	2,467	1,986	A173g without porch
21	SF	A174h	Hip	7:12	1	Yes	No	No	20	12	2,467	1,986	A173h without porch
22	SF	A175G	Gable	7:12	1	No	No	No	11	10	2,467	2,406	Used for no garage Sensitivity Case
23	SF	A176G	Gable	7:12	1	Yes	No	Yes	16	10	2,467	1,986	Used for skylight Sensitivity Case
24	SF	A177G	Gable	7:12	1	Yes	No	No	27	20	2,467	1,986	Used for increased Fenestration Sensitivity
25	SF	A178G	Gable	7:12	1	Yes	No	No	16	10	2,467	1,986	Used for decreased Fenestration Sensitivity
26	SF	K203h	Hip	6:12	2	Yes	No	No	14	11	4,233	3,820	Actual Florida Home- 2 story with no porch
27	SF	K243g	Gable	4:12	2	Yes	No	No	13	10	4,233	3,820	Actual Florida Home- 2 story with no porch
28	SF	K243h	Hip	4:12	2	Yes	No	No	14	11	4,233	3,820	Actual Florida Home- 2 story with no porch
29	SF	K273g	Gable	7:12	2	Yes	No	No	12	9	4,233	3,820	Actual Florida Home- 2 story with no porch
30	SF	K273h	Hip	7:12	2	Yes	No	No	14	11	4,233	3,820	Actual Florida Home- 2 story with no porch
31	MF-I	0024F	Flat	0:12	2				18	15	14,592	14,592	Simple plan; large Group I model used in the 2002 study
32	MF-I	0024G	Gable	4:12	2				21	17	14,592	14,592	Simple plan; large Group I model used in the 2002 study
33	MF-I	0024H	Hip	4:12	2				21	18	14,592	14,592	Simple plan; large Group I model used in the 2002 study
34	MF-I	0027G	Gable	7:12	2				20	17	14,592	14,592	Simple plan; large Group I model used in the 2002 study
35	MF-I	0027H	Hip	7:12	2				21	18	14,592	14,592	Simple plan; large Group I model used in the 2002 study
36	MF-I	S301F	Flat	0:12	3				24	21	35,160	35,160	Actual Fliorida Building- Group I
37	MF-I	S341G	Gable	4:12	3				22	19	35,160	35,160	Actual Fliorida Building- Group I
38	MF-I	S341H	Hip	4:12	3				23	20	35,160	35,160	Actual Fliorida Building- Group I
39	MF-I	S371G	Gable	7:12	3				20	18	35,160	35,160	Actual Fliorida Building- Group I
40	MF-I	S371H	Hip	7:12	3				22	19	35,160	35,160	Actual Fliorida Building- Group I
41	MF-II	0057F	Flat	0:12	5				24	24	33,600	33,600	Simple plan; Group II model used in 2002 study
42	MF-II	WW31F	Flat	0:12	3				14	12	28,620	28,620	Actual Florida Building-Group II
43	MF-III	0087F	Flat	0:12	8				24	24	53,760	53,760	Simple plan; Group III model used in 2002 study
44	MF-III	SB31F	Flat	0:12	10				28	28	240,000	240,000	Actual Florida Building-Group Iii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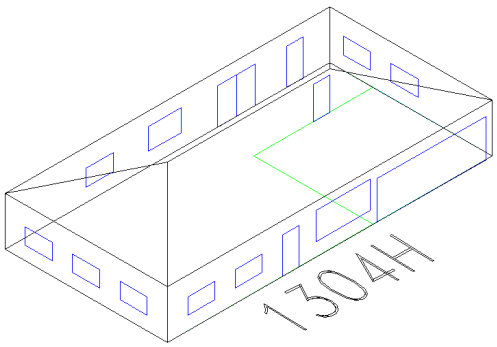
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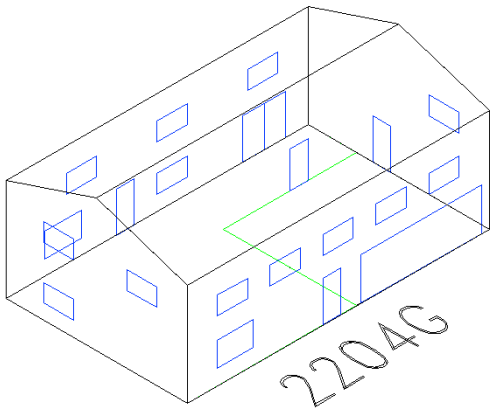
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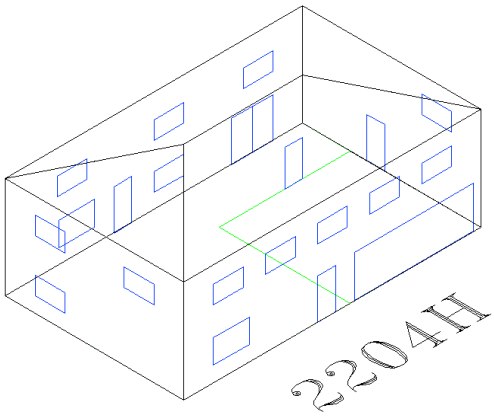
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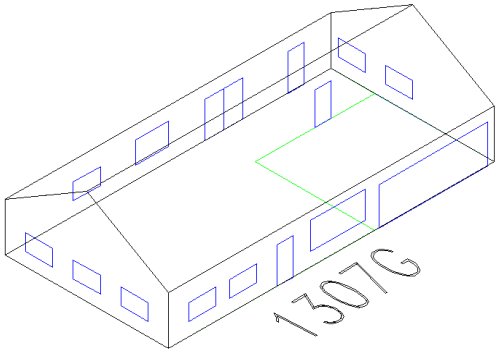
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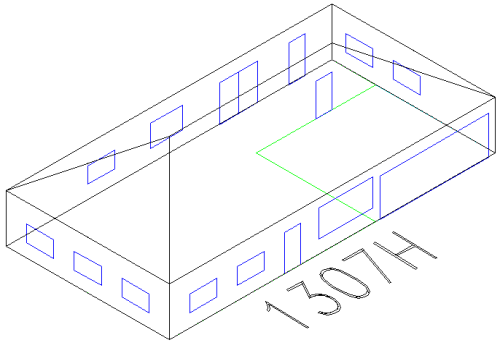
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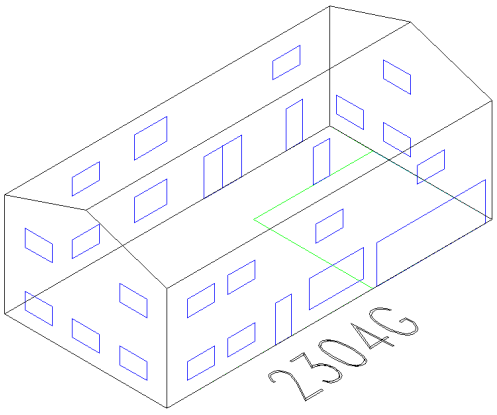
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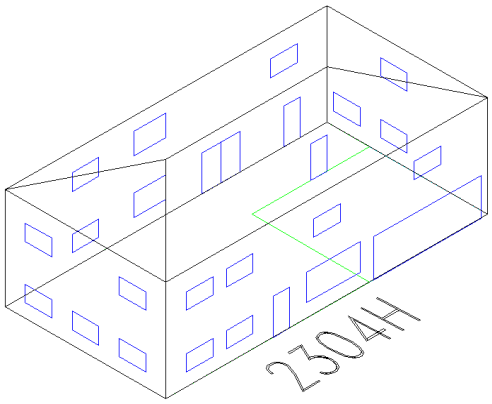
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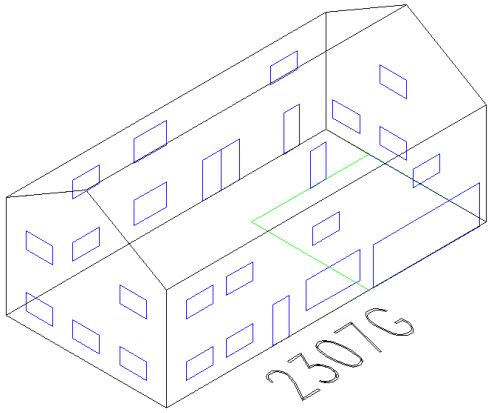
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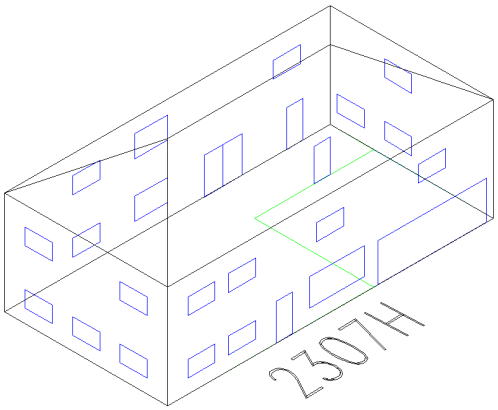
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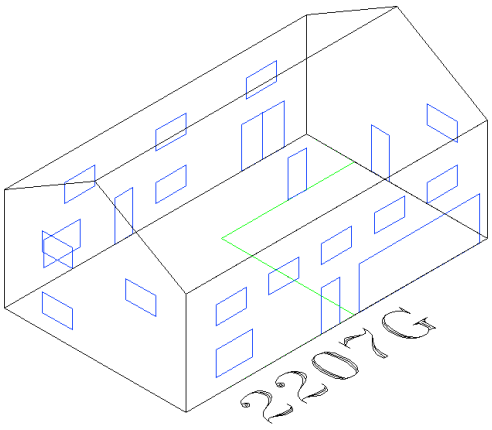
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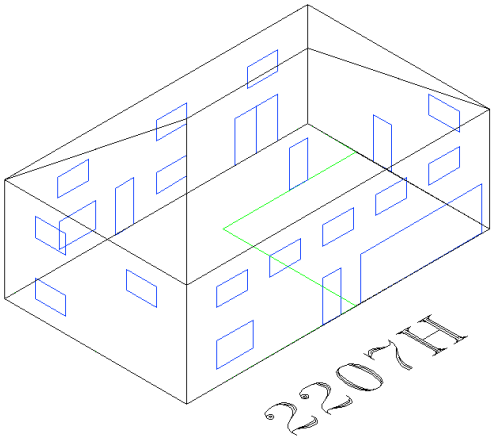
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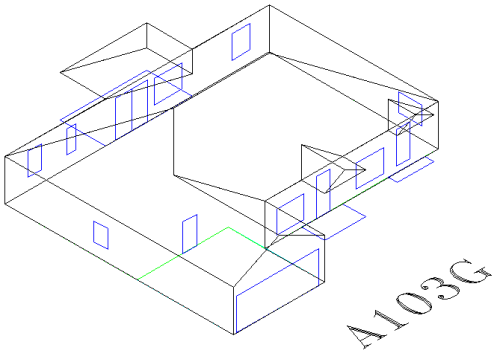
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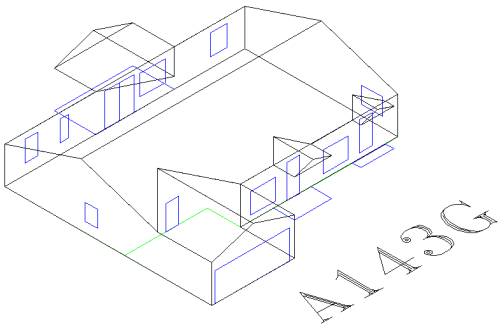
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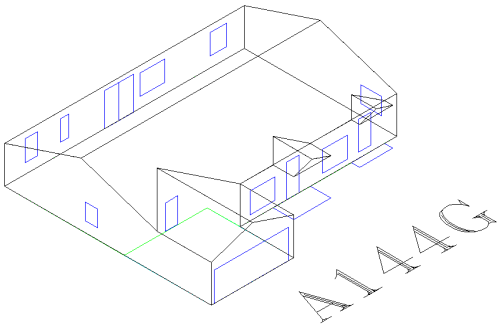
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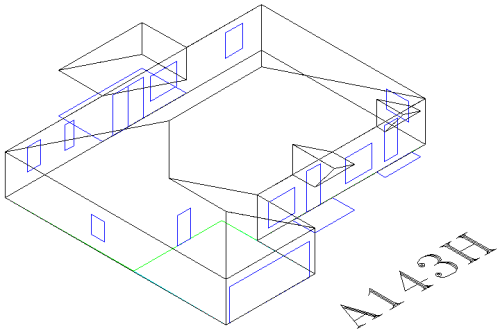
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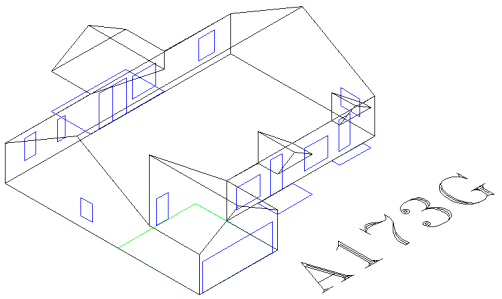
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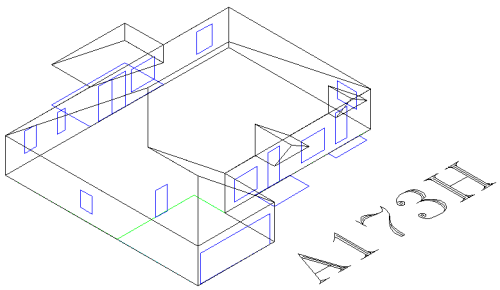
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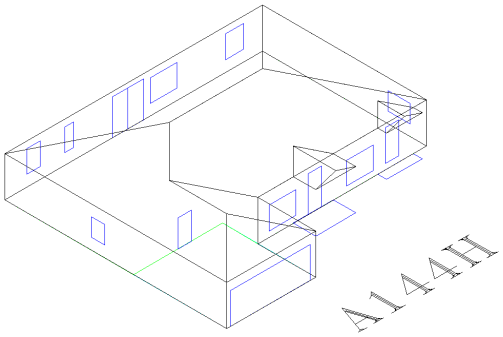
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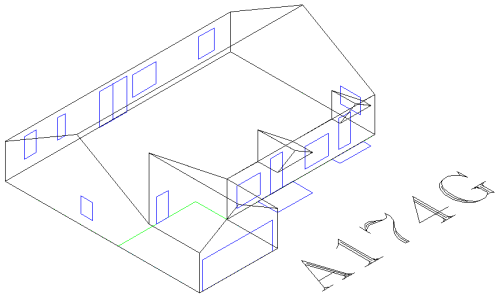
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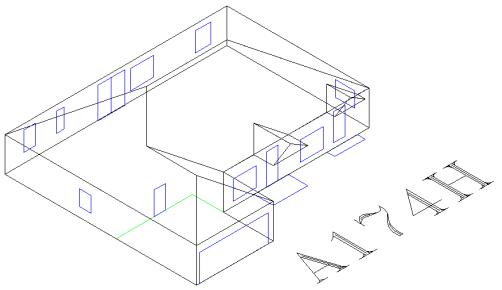
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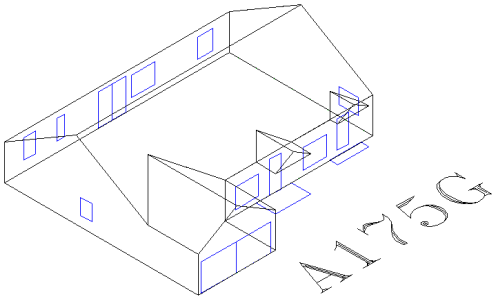
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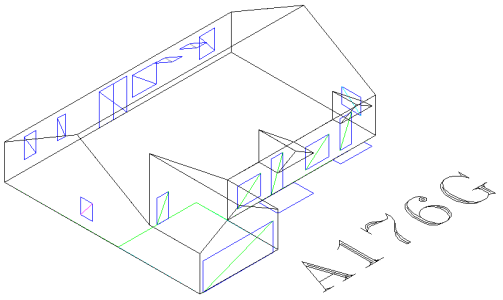
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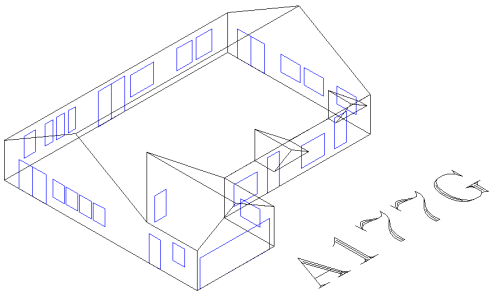
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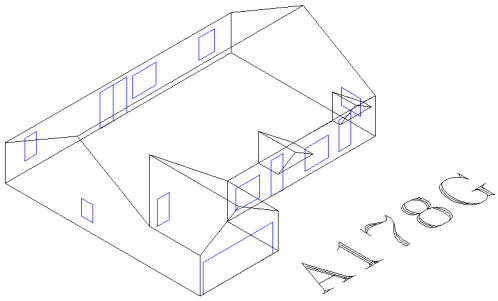
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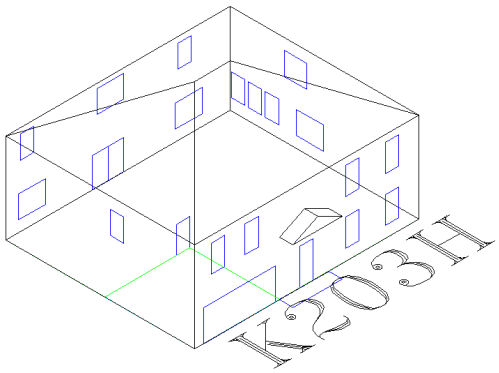
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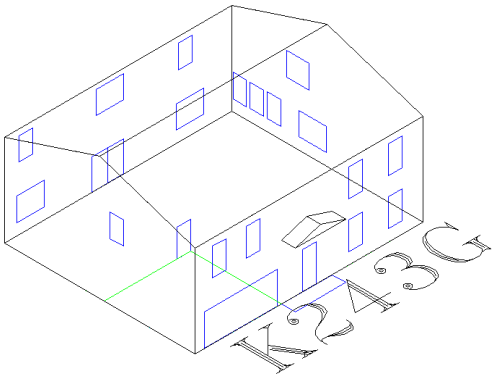
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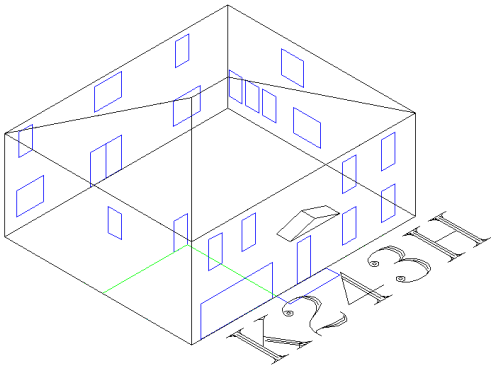
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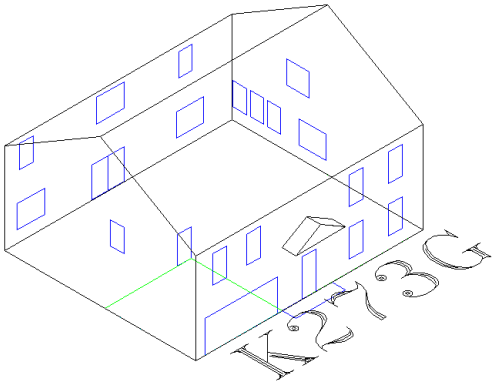
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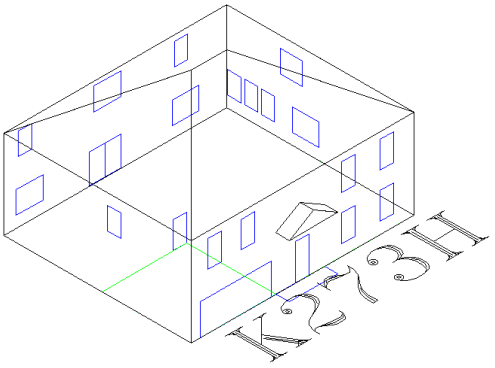
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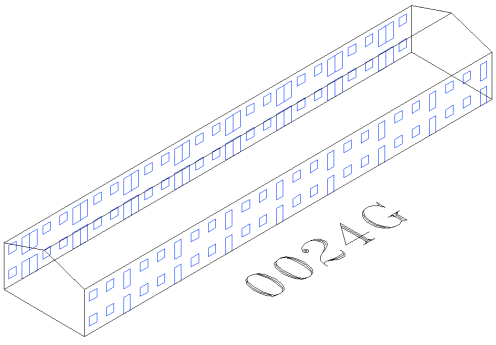
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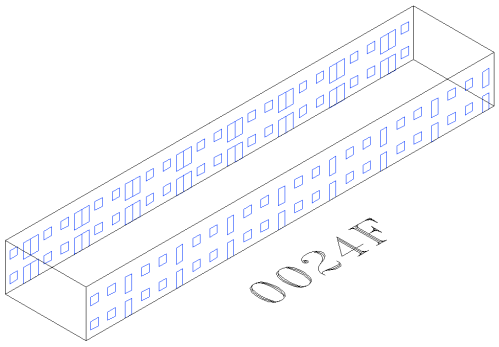
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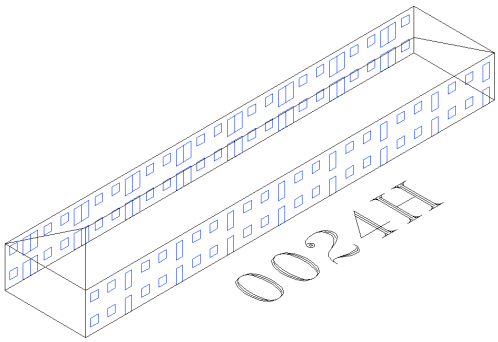
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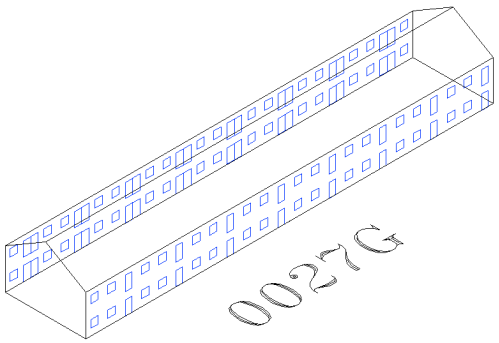
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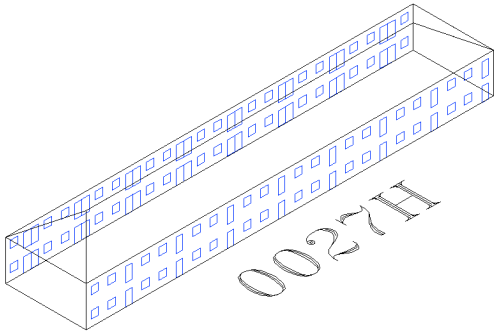
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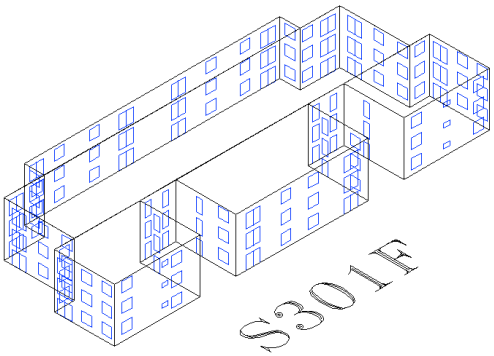
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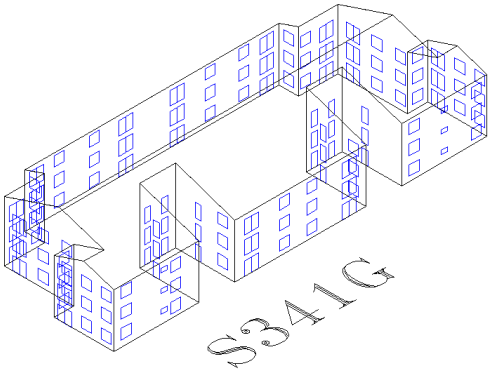
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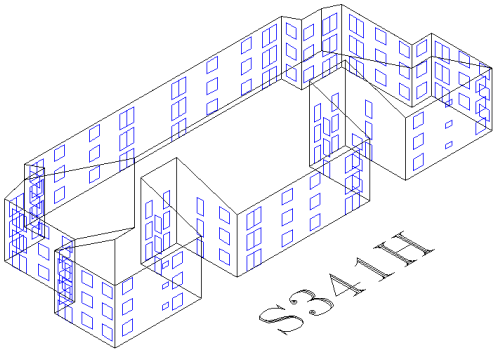
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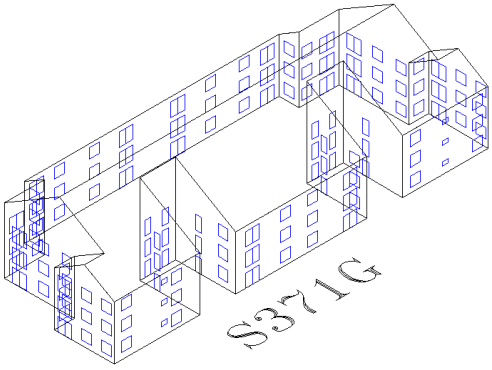
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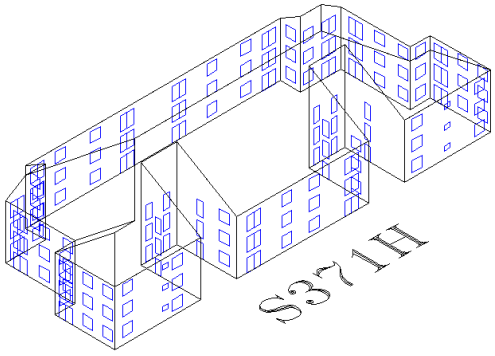
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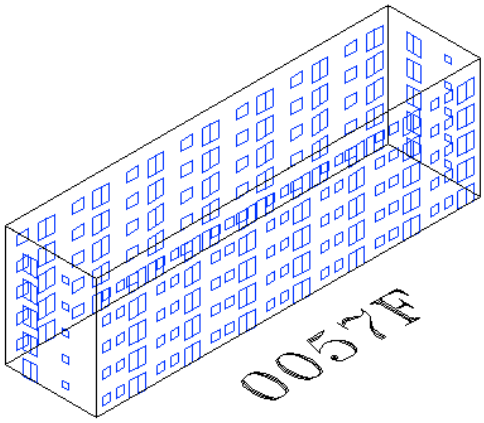
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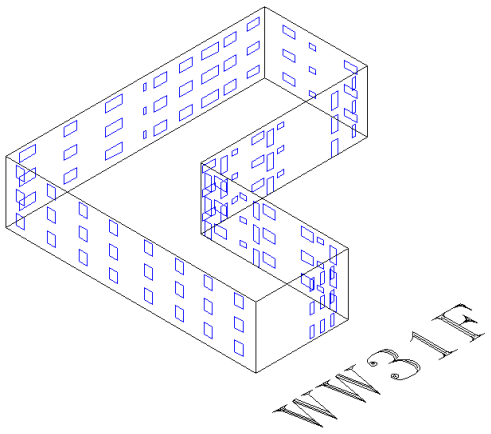
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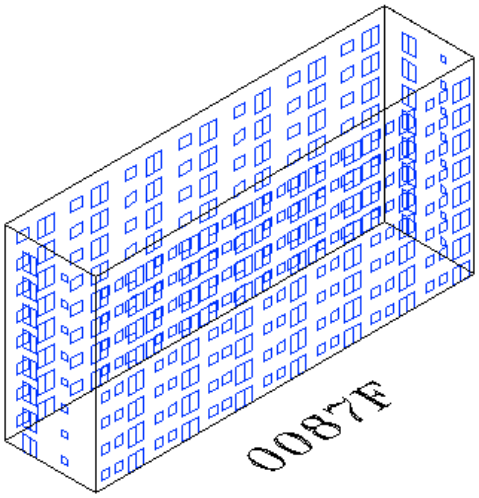
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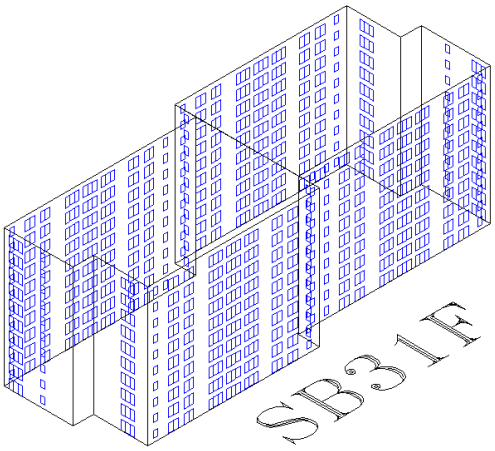

SB31F

Appendix D. Example 2006 FBC Design Calculations

D.1. Introduction

This appendix presents example 2006 FBC wind resistive design calculations that have been completed on modeled buildings. The buildings correspond to Model Index Numbers 1 and 3 in Table 2-5, which corresponds to Models 1304G and 1307G. These models are for a single-story, single-family home. Designs are presented for the 4:12 and 7:12 roof slopes. Comparisons of key component resistances derived from the allowable design options are also presented so that the reader can get an appreciation of the large range of allowable design values that can be used in the design of identical structures using accepted design approaches. The FBC allows both prescriptive and performance-based designs for detached one- and two-family dwellings and multiple single family dwellings (townhomes) not more than three stories in height with a separate means of egress. Large multi-family buildings must be designed using performance-based methods given in *FBC Building*.

D.2. Design Options

There are three interpretations in the FBC that warrant some discussion with respect to wind loads. The first is the FBC definition of exposure categories; the second is the definition of "openings" and how that affects the assumption of enclosed vs. partially-enclosed designs; the third regards the truss design load. The following paragraphs discuss these issues.

D.2.1. Definition of Terrain Exposure[5]

The FBC has now adopted the same definition of Exposure C as appears in the text of ASCE 7-98. In the FBC 2001, the definition of terrain exposure was different than that of ASCE 7. A simplified definition of terrain was used in which Terrain Exposure C included the barrier islands and areas within 1500 feet of the coast. All other locations in Florida were designated as Terrain B. Hence, the 2001 FBC did not require buildings with open exposure and away from the coast, to be designed for Exposure C wind loads.

The FBC adopted terrain exposure definitions similar to ASCE 7 in 2006. ASCE 7 uses Terrain C as the default terrain unless the site and surrounding roughness warrant Terrain Exposure B. This means that buildings located next to large open areas in Florida should be considered in Terrain C, regardless of distance from the coast.

D.2.2. Partially Enclosed vs. Enclosed Design

Building codes define three conditions regarding the effect of whether the wind is able to enter a building and change the loading pattern on the building components. The first is an "Enclosed" building where the envelope is completely closed, and only wind "leaking" around doors, windows, framing, etc. is allowed to affect the interior of the building. The second condition is called an "Open" building such as a stadium grand stand where wind can freely enter the inside of the structure.

In between these two conditions is the third case, which is a "Partially Enclosed" building, where openings are assumed to exist in one or more faces of the building. These openings allow the wind to create pressures inside the building. These "internal" pressures for partially enclosed designs are typically

[5] ASCE-7 and wind engineers use the term "Exposure" to define the earth's surface roughness for purposes of grouping this roughness into several distant categories for wind load estimation. Insurers need to be aware of this use of the term "Exposure" when reading building code and wind engineering literature. To avoid confusion, we attempt to use "Terrain" in this report to refer to surface roughness.

larger than the internal pressures in an enclosed building. Hence, partially enclosed designs that are based on larger internal pressures typically result in individual parts of the structure being stronger than if designed to an "enclosed" condition. However, the openings (windows, doors, etc.) in partially enclosed designs are vulnerable to wind-borne debris impact failures and the resulting wind and rain water damage to the building interior and contents. Determining which condition is appropriate for a given building depends on the number and size of the openings in a building.

Prior to amendments to the 2006 FBC, partially enclosed designed were allowed in the Wind-Borne Debris Region of the FBC (see Section 2.2), with the exception of the HVHZ. Beginning in 2008, partially enclosed designs are not allowable and all buildings must have opening protection. Hence, all new designs in the Wind-Borne Debris Region will have all glazed openings protected for debris impact. These buildings will perform better than partially enclosed designs and will have lower losses.

The partially enclosed designs that we developed in the 2002 loss relativity studies are still applicable to the 2001 to 2006 FBC building code era and will be used in this study. Since new designs cannot consider the partially enclosed option, the design information presented in this appendix does not cover partially enclosed.

D.2.3. Effect of Loading Assumptions in Truss Strap Design

A designer is allowed two methods of calculating the loads on the roof-to-wall connection. The designer can choose to: (1) use prescriptive requirements, or (2) design the connection using performance-based methods.

One set of loads in the code is called Components and Cladding (C&C) loads and these are to be applied to any cladding or member that receives wind loads directly from the wind. These loading pressures take into account the lack of correlation of the wind gusts over larger and larger areas. The other set of loads in the code are called Main Wind Force Resisting System (MWFRS) loads and are intended to calculate the effect of loads acting on several surfaces at once. Much discussion and debate among design professionals over which loading set is appropriate for roof trusses has ensued over the years.

The ASCE 7-98 and 7-02 documents indicate that trusses are to be considered as both C&C loading and MWFRS loading (see page 243 of ASCE 7-98 commentary). The commentary describes the situation where long span trusses should be designed for MWFRS loads and individual members of the truss designed for C&C loads. Unfortunately, the commentary does not discuss what is appropriate for the straps holding the truss to the wall, nor does it define what constitutes a long span truss. Section 6.5.12.1.3 of ASCE 7-98, 7-02, and 7-05 indicate a threshold of 700 square feet of tributary area for considering a component to be designed with MWFRS loads. From this threshold, a logical argument could be made that most residential trusses are not large enough to qualify for the MWFRS loads, and therefore should be designed for C&C loads, and subsequently, the strap size chosen to be consistent with C&C loads. For residential structures, both the MWFRS and the C&C loads should be checked, and the larger of the two chosen. Typically, for residential construction, the C&C loads are significantly higher than the MWFRS loads.

The prescriptive requirements for truss uplift given in the AFPA Wood frame construction manual are based on the MWFRS lowrise provisions of as defined in ASCE 7-98. The prescriptive uplift requirements given in the 2006 version of the FBC are also based on the MWFRS loads as given in ASCE 7-98.

The prescriptive truss uplift requirements of both the IBHS and FCPA guides are based on the SBC97 (or SBC95) building code, and clearly state in each document that the truss strap design has been completed with MWFRS loads.

While the C&C loads produce larger uplift forces than the MWFRS loads, the loss relativity results indicate that the effect of the design method for the uplift requirements on the roof-to-wall connection has a relatively minor effect on loss costs. Therefore, the loss relativity results presented in this study focus on the MWFRS results. In addition, it is our understanding that industry practice employs the MWFRS loads.

D.3. Model Design Parameters

ARA has performed design calculations for wind loads on various components of a wood frame and masonry version of the house in this study. The following key components that affect the wind resistance of the building will vary depending on which wind speed the building is designed for:

- Roof Deck Nailing Pattern
- Window and Door Design Pressure
- Roof Wall Tie Down

In addition these other items have also been examined:

- Roof Cover
- Opening Protection
- Wood Frame Wall Lumber Size
- Masonry Wall Vertical Reinforcement Spacing
- Foundation

The design calculations for one of the houses at 130 mph design wind speed are shown at the end of this appendix. These calculations were repeated for all wind speed/exposure combinations that exist in Florida. Table D-1, Table D-2, and Table D-3 summarize the results code calculations for the roof-wall uplift requirements and roof sheathing resistance as a function of code era (*FBC* 2001, 2004-2005 and 2006) as well as the equivalent resistances resulting from the use of the allowable prescriptive requirements. For implementation of the relativities developed in this report, the intermediate building code era (2004-2005) has been omitted. This simplification results in two post-FBC building code eras – one corresponding to the 2001 FBC and the other corresponding to the 2006 FBC.

The minimum nailing requirements resulting from the use of the various prescriptive codes as well as those resulting from a design of the connections using the various editions of the FBC are given in the Tables. All designs are presented for an enclosed building configuration. Nailing requirements for the roof sheathing are given for a building with roof slopes of both 4:12 and 7:12. We note that when using the prescriptive requirements, the same nailing requirements are used for all roof slopes. The model building used in these calculations is the same as buildings 1304G and 1307G in Table 2-5. The building length is 60 feet and the clear span of the trusses is 30 feet.

The design calculations indicate that a minimum nail size of 8d should be used throughout the state. The nailing pattern for the roof varies from the standard 6″/12″ pattern in the lower wind speed zones in the state, to the 6″/6″ spacing in the high wind zone areas. In all of these designs, the nailing pattern at the edge of the roof is assumed to drop to a 4″ spacing next to the gable end (if appropriate). In the 2004-2005 Edition (Table D-2) of the *FBC* for wind speeds greater than 110 mph, a minimum spacing of 6″/6″ (with 4″/4″ spacing in the corner zones) is required, even if calculations indicate a less stringent spacing is satisfactory. In the 2006 Edition, (Table D-3) for wind speeds greater than 100 mph the residential building code required that ring shank nails be used, again, regardless of whether or not engineering based calculations suggested regular nails could be used.

The hurricane strap size has been calculated for a truss using MWFRS loads. Both end trusses and interior trusses were calculated for the building. Table D-1 through Table D-3 present the uplift reaction for the interior and end trusses of the building with roof slopes of 4:12 and 7:12.

Table D-4 through Table D-6 presents a summary of the design of the key wind resistant features (roof-wall connections, sheathing attachments and window pressures) of the model house for the buildings designed to the 2001 *FBC* and the 2006 *FBC*. Table D-7 though Table D-9 present the wall designs. Note that the building designs computed using the 2004 *FBC* with the December 2006 amendments will be the same as those computed using the 2007 *FBC*, since none of the changes to the 2007 *FBC* impact these designs.

D.4. Effect of Wall Construction on Wall Failures

ARA also designed a wood frame wall and a masonry wall for each of the three buildings in this study. The wood frame wall was examined for capacity in bending due to wind loads, axial loads from the roof and shear loads along the length of the wall. The design calculations indicate that a standard 2x4 wall at 16 inch spacing is adequate if an appropriate grade of wood is used to carry the wind loads in most parts of the state.

ARA analyzed the new construction homes with wood frame walls and masonry walls in the 2002 relativity study and found that the wall construction has little effect on the loss relativity. Our models show that the failure rates of wood frame are higher than those of masonry. The model also indicates that the wall failures are correlated with whole roof failures, which result in losses that approach the coverage limit. The FBC requires that any structures that has more than 50% damage that the entire building must be built to the current requirements of the FBC. Hence, we believe that the increased strength of masonry walls on loss costs is minimal. Houses with masonry walls may have other design features that help them perform better, but we do not believe that the increase in wall strength is a significant factor.

D.5. Effect on Foundation Design

Calculations of the anchor bolts required to resist the wind loads according to the FBC were completed. As demonstrated in the 2002 study (ARA, 2002a), the failure of the foundation affects the relativities when the foundation relies only on the weight of the structure to resist the wind shear and uplift forces. Any type of rebar or anchor bolts will essentially eliminate the foundation failure's effect on the relativities. Since all foundations built according to the FBC will be restrained in some fashion, the foundation type has not been included as a variable in the new construction matrix.

D.6. Mathcad Example Code Calculations

Table D-10 contains a sample set of design calculations for new construction using the wind loads given in the FBC. This one story house is 60 feet long and has a truss clear span of 30 feet with an eave height of 13 feet 9 inches and is the same building as 1304G/1307G in Table 2–5. Input parameters are the design wind speed and terrain exposure according to the FBC. In particular, the building is assumed to be situated in Terrain Exposure C, in a location with a design wind speed of 130 mph. An enclosed building design is assumed. Dimensions for doors, windows, sliders and garage doors are given in the calculations. The following parameters are examined in these calculations:

- Fenestration design pressures,
- Roof deck nailing,
- Roof –wall connections,
- Wood wall design (if applicable),

- Masonry wall design (if applicable) and
- Anchor bolt design

The parameters above have been calculated for each wind and exposure combination for Building 1304G/1307G.

Table D-1. Truss and Sheathing Uplift Requirements from FBC 2001

Prescriptive Design of Strap Size and Nailing Pattern for Building 1304G/1307G in 2001[5]														
		FBC Enclosed (Design) 4:12		FBC Enclosed (Design) 7:12		Prescriptive Standards								
						FBC		SSTD 10		FC&PA		AF&PA		
Wind Speed	Exp.	Strap corner / interior (lbf)	Roof Nail Spacing	Strap corner / interior (lbf)	Roof Nail Spacing	Strap corner / interior (lbf)	Roof Nail Spacing	Strap corner / interior (lbf)	Roof nail Spacing	Strap corner / interior (lbf)	Roof nail Spacing	Strap corner / interior (lbf)[4]	Roof nail Spacing (edge panel)	Roof nail Spacing (interior panel)
100	B	346/280	8d@6"/12" , 8d@6"/12" at gable end	346/280	8d@6"/12" , 8d@6"/12" at gable end	N/A	8d@ 6"/12"	(293/205)[7]	8d[1]@ 6"/12"	(456/262)[7]	8d[9] or 10d[10] @6"/12"[7,8]	344/258	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	451/378	8d@6"/12" , 8d@6"/12" at gable end	451/378	8d@6"/12" , 8d@6"/12" at gable end	N/A	8d@ 6"/12"	401/280	8d[1]@ 6"/6"	637/398	8d[9] or 10d[10] @6"/12"[7,8]	595/466	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
110	B	457/377	8d@6"/12" , 8d@6"/12" at gable end	457/377	8d@6"/12" , 8d@6"/12" at gable end			293/205	8d[1]@ 6"/6"	456/262	8d[9] or 10d[10] @6"/12"[7,8]	480/360	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	592/495	8d@6"/12" , 8d@6"/12" at gable end	592/495	8d@6"/12" , 8d@6"/12" at gable end			520/364	8d[1]@ 6"/6"	840/550	8d[9] or 10d[10] @6"/12"[7,8]	784/588	8d or 10d3@ 6"/6"	8d or 10d[3]@ 6"/12"
120	B	578/483	8d@6"/12" , 8d@6"/12" at gable end	578/483	8d@6"/12" , 8d@6"/12" at gable end			401/280	8d[1]@ 6"/6"	637/398	8d[9] or 10d[10] @6"/12"[7,8]	628/471	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	738/623	8d@6"/12" , 8d@6"/12" at gable end	738/623	8d@6"/12" , 8d@6"/12" at gable end							992/744	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
130	B	710/599	8d@6"/12" , 8d@6"/12" at gable end	710/599	8d@6"/12" , 8d@6"/12" at gable end			520/364	8d[1]@ 6"/6"	840/540	8d[9] or 10d[10] @6"/12"[7,8]	791/593	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	898/763	8d@6"/9.6" , 8d@6"/9.6" at gable end	898/763	8d@6"/12" , 8d@6"/12" at gable end									
140	B	851/723	8d@6"/9.6" , 8d@6"/9.6" at gable end	851/723	8d@6"/12" , 8d@6"/12" at gable end							966/725	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
	C	1070/914	8d@6"/8" , 8d@6"/8" at gable end	1070/914	8d@6"/12" , 8d@6"/12" at gable end									
140 HVHZ	C	1070/914	8d@6"/6" , 10d@4"/4" at gable end	1070/914	8d@6"/6" , 10d@4"/4" at gable end	N/A	8d[6]@ 6"/6"							
146 HVHZ	C	1179/1009	8d@6"/6" , 10d@4"/4" at gable end	1179/1009	8d@6"/6" , 10d@4"/4" at gable end	N/A	8d[6]@ 6"/6"							
150	B	1004/856	8d@6"/8" , 8d@6"/8" at gable end	1004/856	8d@6"/12" , 8d@6"/12" at gable end									
150	C	1255/1075	8d@6"/6.86" , 8d@6"/6.86" at gable end	1255/1075	8d@6"/12" , 8d@6"/12" at gable end									

[1] Ring shank in zone 3
[2] Use 4" at gable ends
[3] Box nail
[4] Dead load is based on 15 psf rather than 10 psf
[5] All nails are common nails unless noted otherwise
[6] 10d at gable ends @4" O.C.
[7] Next highest wind speed used for this value
[8] Edges of interior panels must be at 6" O.C.
[9] For 7/16" or 15/32" sheathing
[10] For 1/2" or 19/32" or 5/8" sheathing

Table D-2. Truss and Sheathing Uplift Requirements from FBC 2004-2005

Prescriptive Design of Strap Size and Nailing Pattern for Building 1304G/1307G in 2004, 2005[5]															
Wind Speed	Exp.	FBC Enclosed (Design) 4:12 Roof		FBC Enclosed (Design) 7:12 Roof		Prescriptive Standards									
						FBC		SSTD 10		FC&PA		AF&PA			
		Strap corner / interior (lbf)	Roof Nail Spacing	Strap corner / interior (lbf)	Roof Nail Spacing	Strap corner / interior (lbf)	Roof Nail Spacing	Strap corner / interior (lbf)	Roof nail Spacing	Strap corner / interior (lbf)	Roof nail Spacing	Strap corner / interior (lbf)[13]	Roof nail Spacing (edge panel)	Roof nail Spacing (interior panel)
100	B	346/280	8d@6"/12" , 8d@6"/12" at gable end	280/280	8d@6"/12" , 8d@6"/12" at gable end	327/229	8d@ 6"/12"	(293/205)[9]	8d[1]@ 6"/12"	(456/262)[9]	8d11 or 10d[12] @6"/12"[9,10]	344/258	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	451/378	8d@6"/12" , 8d@6"/12" at gable end	378/378	8d@6"/12" , 8d@6"/12" at gable end	396/277	8d@ 6"/12"	401/280	8d[1]@ 6"/6"	637/398	8d11 or 10d[12] @6"/12"[9,10]	595/466	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
110	B	457/377	8d@ 6"/6"[8]	377/377	8d@ 6"/6"[8]	438/307	8d@ 6"/6"[8]	293/205	8d[1]@ 6"/6"	456/262	8d11 or 10d[12] @6"/12"[9,10]	480/360	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	592/495	8d@6"/12" , 8d@6"/12" at gable end	495/495	8d@6"/12" , 8d@6"/12" at gable end	530/371	[7]	520/364	8d[1]@ 6"/6"	840/550	8d11 or 10d[12] @6"/12"[9,10]	784/588	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
120	B	578/483	8d@ 6"/6"[8]	483/483	8d@ 6"/6"[8]	[7]	8d@ 6"/6"[8]	401/280	8d[1]@ 6"/6"	637/398	8d11 or 10d[12] @6"/12"[9,10]	628/471	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	738/623	8d@6"/12" , 8d@6"/12" at gable end	623/623	8d@6"/12" , 8d@6"/12" at gable end							992/744	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
130	B	710/599	8d@ 6"/6"[8]	599/599	8d@ 6"/6"[8]	[7]	8d@ 6"/6"[8]	520/364	8d[1]@ 6"/6"	840/540	8d11 or 10d[12] @6"/12"[9,10]	791/593	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	898/763	8d@6"/9.6" , 8d@6"/9.6" at gable end	763/763	8d@6"/12" , 8d@6"/12" at gable end							1217/912	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
140	B	851/723	8d@ 6"/6"[8]	723/723	8d@ 6"/6"[8]	[7]	8d@ 6"/6"[8]					966/725	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
	C	1070/914	8d@6"/8" , 8d@6"/8" at gable end	914/914	8d@6"/12" , 8d@6"/12" at gable end							1460/1095	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
140 HVHZ	C	1070/914	8d[4,6]@ 6"/6"	914/914	8d[4,6]@ 6"/6"	[7]	8d[4,6]@ 6"/6"					1460/1095	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
146 HVHZ	C	1179/1009	8d[4,6]@ 6"/6"	1009/1009	8d[4,6]@ 6"/6"	[7]	8d[4,6]@ 6"/6"					1722/1291[9]	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
150	B	1004/856	8d@6"/8" , 8d@6"/8" at gable end	856/856	8d@6"/12" , 8d@6"/12" at gable end							1153/865	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
150	C	1255/1075	8d@6"/6.86" , 8d@6"/6.86" at gable end	1075/1075	8d@6"/12" , 8d@6"/12" at gable end							1722/1291		

[1] Ring shank in zone 3
[2] Use 4" at gable ends
[3] Box nail
[4] Ring shank
[5] All nails are common nails unless noted otherwise
[6] Ring shank nails @4" at gable ends or 10d nails @4" at gable ends
[7] Value not tabulated
[8] 4"/4" Spacing for component and cladding at edge strip in zone 3 if FBC, Building is used
[9] Next highest wind speed used for this value
[10] Edges of interior panels must be at 6" O.C.
[11] For 7/16" or 15/32" sheathing
[12] For 1/2" or 19/32" or 5/8" sheathing
[13] Dead load is based on 15 psf rather than 10 psf

Table D-3. Truss and Sheathing Uplift Requirements from 2006 FBC Codes

Prescriptive Design of Strap Size and Nailing Pattern for Building 1304G/1307G in 2006[5]														
Wind Speed	Exp.	FBC Enclosed (Design) 4:12 Roof		FBC Enclosed (Design) 7:12 Roof		Prescriptive Standards								
						FBC		IBHS		FC&PA		AF&PA		
		Strap corner / interior (lbf)	Roof Nail Spacing	Strap corner / interior (lbf)	Roof Nail Spacing	Strap corner / interior (lbf)	Roof Nail Spacing	Strap corner/ interior (lbf)[7,18]	Roof nail Spacing	Strap corner / interior (lbf)	Roof nail Spacing	Strap corner / interior (lbf)[17]	Roof nail Spacing (edge panel)	Roof nail Spacing (interior panel)
100	B	346/280	8d@ 6"/6"	280/280	8d@ 6"/6"	342/191	(8d@ 6"/6")[9] or (8d@ 6"/12")[11,12]	468/328	8d[1]@ 6"/6"	(456/262)[13]	8d[15] or 10d[16] @6"/12"[13,14]	344/258	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	451/378	8d@ 6"/6"	378/378	8d@ 6"/6"	552/340	(8d@ 6"/6")[9] or (8d@ 6"/12")[11,12]	642/450	8d[1]@ 6"/6"	637/398	8d[15] or 10d[16] @6"/12"[13,14]	595/466	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
110	B	457/377	8d[11,12]@ 6"/6"[8]	377/377	8d[11,12]@ 6"/6"[8]	452/268	8d[11,12]@ 6"/6"[8]	556/390	8d[1]@ 6"/6"	456/262	8d[15] or 10d[16] @6"/12"[13,14]	480/360	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	592/495	8d[11,12]@ 6"/6"	495/495	8d[11,12]@ 6"/6"	706/449	8d[11,12]@ 6"/6"	806/564	8d[1]@ 6"/6"	840/550	8d[15] or 10d[16] @6"/12"[13,14]	784/588	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
120	B	578/483	8d[11,12]@ 6"/6"[8]	483/483	8d[11,12]@ 6"/6"[8]	572/354	8d[11,12]@ 6"/6"[8]	642/450	8d[1]@ 6"/6"	637/398	8d[15] or 10d[16] @6"/12"[13,14]	628/471	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
	C	738/623	8d[11]@ 6"/6"	623/623	8d[11]@ 6"/6"	875/568	8d[11]@ 6"/6"	968/676	8d[1]@ 6"/6"			992/744	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
130	B	710/599	8d[11]@ 6"/6"[8]	599/599	8d[11]@ 6"/6"[8]	702/447	8d[11]@ 6"/6"[8]	804/564	8d[1]@ 6"/6"	840/540	8d[15] or 10d[16] @6"/12"[13,14]	791/593	8d or 10d[3]@ 6"/6"	8d or 10d[3]@ 6"/12"
130	C	898/763	8d[11]@ 6"/6"	763/763	8d[11]@ 6"/6"[8]	1058/699	8d[11]@ 6"/6"[8]					1217/912	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
140	B	851/723	8d[11]@ 6"/6"[8]	723/723	8d[11]@ 6"/6"[8]	843/547	8d[11]@ 6"/6"[8]	968/676	8d[1]@ 6"/6"			966/725	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
	C	1070/914	8d[11]@ 6"/6"	914/914	8d[11]@ 6"/6"	1256/839	8d[11]@ 6"/6"					1460/1095	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
140 HVHZ	C	1070/914	8d[1,6,11]@ 6"/6"	914/914	8d[1,6,11]@ 6"/6"	1256/839	8d[1,6,11]@ 6"/6"					1460/1095	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
146 HVHZ	C	1179/1009	8d[1,6,11]@ 6"/6"	1009/1009	8d[1,6,11]@ 6"/6"	1468/1061[13]	8d[1,6,11]@ 6"/6"					1722/1291[1,3]	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
150	B	1004/856	8d[11]@ 6"/6"	856/856	8d[11]@ 6"/6"	996/654	8d[11]@ 6"/6"					1153/865	8d or 10d[3]@ 4"/4"	8d or 10d[3]@ 6"/12"
150	C	1255/1075	8d[11]@ 6"/6"	1075/1075	8d[11]@ 6"/6"	1468/1061	8d[11]@ 6"/6"					1722/1291		

[1] Ring shank
[2] Use 4" at gable ends
[3] Box nail
[4] Value not tabulated
[5] All nails are common nails unless noted otherwise
[6] Ring shank nails @4" at gable ends or 10d nails @4" at gable ends
[7] All tabulated exposure C values are assumed to be equivalent to exposure B at 140 mph
[8] 4"/4" Spacing for component and cladding at edge strip in zone 3 according to FBC, *Building*
[9] common nail or hot dipped galvanized
[10] Provisions for this wind speed not given. Higher wind speed used in its place
[11] FBC *Residential* ring shank with 0.113 inch nominal shank diam., 0.012 ring diam. over shank diam., 16-20 rings per inch, 0.280 in full round head diam., 2 inch nail length
[12] FBC *Residential* allows 6"/12" in zone 1 and 2
[13] Next highest wind speed used for this value
[14] Edges of interior panels must be at 6" O.C.
[15] For 7/16" or 15/32" sheathing
[16] For 1/2" or 19/32" or 5/8" sheathing
[17] Dead load is based on 15 psf rather than 10 psf
[18] Values tabulated have been reduced by an additional 20% as per the IBHS due to eave height being less than 12 feet

Table D-4. Design parameters for model building 1304G/1307G computed using FBC 2001 (enclosed design)

Gable Roof Design Values for Building 1304G/1307G in 2001[1]									
		FBC Enclosed (Design) 4:12 Roof				FBC Enclosed (Design) 7:12 Roof			
Wind Speed	Exp.	Design Strap C&C corner / interior (lbf)	Design Strap MWFRS corner / interior (lbf)	Roof Nail Spacing	Window Design pressure (psf)	Design Strap C&C corner / interior (lbf)	Design Strap MWFRS corner / interior (lbf)	Roof Nail Spacing	Window Design pressure (psf)
100	B	542/378	346/280	8d@6"/12" , 8d@6"/12" at gable end	-21	360/305	346/280	8d@6"/12" , 8d@6"/12" at gable end	-21
	C	696/496	451/378	8d@6"/12" , 8d@6"/12" at gable end	-25	473/407	451/378	8d@6"/12" , 8d@6"/12" at gable end	-25
110	B	694/495	457/377	8d@6"/12" , 8d@6"/12" at gable end	-25	473/407	457/377	8d@6"/12" , 8d@6"/12" at gable end	-25
	C	879/638	592/495	8d@6"/12" , 8d@6"/12" at gable end	-30	611/531	592/495	8d@6"/12" , 8d@6"/12" at gable end	-30
120	B	861/623	578/483	8d@6"/12" , 8d@6"/12" at gable end	-30	597/518	578/483	8d@6"/12" , 8d@6"/12" at gable end	-30
	C	1081/794	738/623	8d@6"/12" , 8d@6"/12" at gable end	-36	762/666	738/623	8d@6"/12" , 8d@6"/12" at gable end	-36
130	B	1041/763	710/599	8d@6"/12" , 8d@6"/12" at gable end	-35	732/639	710/599	8d@6"/12" , 8d@6"/12" at gable end	-35
	C	1300/963	898/763	8d@6"/9.6" , 8d@6"/9.6" at gable end	-42	925/813	898/763	8d@6"/12" , 8d@6"/12" at gable end	-42
140	B	1236/913	851/723	8d@6"/9.6" , 8d@6"/9.6" at gable end	-41	878/770	851/723	8d@6"/12" , 8d@6"/12" at gable end	-41
	C	1536/1145	1070/914	8d@6"/8" , 8d@6"/8" at gable end	-49	1101/971	1070/914	8d@6"/12" , 8d@6"/12" at gable end	-49
140 HVHZ	C	1536/1145	1070/914	8d@6"/6" , 10d@4"/4" at gable end	-49	1101/971	1070/914	8d@6"/6" , 10d@4"/4" at gable end	-49
146 HVHZ	C	1686/1261	1179/1009	8d@6"/6" , 10d@4"/4" at gable end	-53	1214/1072	1179/1009	8d@6"/6" , 10d@4"/4" at gable end	-53
150	B	1446/1075	1004/856	8d@6"/8" , 8d@6"/8" at gable end	-47	1034/911	1004/856	8d@6"/12" , 8d@6"/12" at gable end	-47
150	C	1790/1341	1255/1075	8d@6"/6.86" , 8d@6"/6.86" at gable end	-56	1292/1142	1255/1075	8d@6"/12" , 8d@6"/12" at gable end	-56

[1]All nails are common nails unless noted otherwise

Table D-5. Design parameters for model building 1304G/1307G computed using FBC 2001 (partially enclosed design)

Gable Roof Design Values for Building 1304G/1307G in 2001[1]									
Wind Speed	Exp.	FBC Partially Enclosed (Design) 4:12 Roof				FBC Partially Enclosed[2] (Design) 7:12 Roof			
		Design Strap C&C corner / interior (lbf)	Design Strap MWFRS corner / interior (lbf)	Roof Nail Spacing	Window Design pressure (psf)	Design Strap C&C corner / interior (lbf)	Design Strap MWFRS corner / interior (lbf)	Roof Nail Spacing	Window Design pressure (psf)
100	B	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
110	B	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
120	B	1104/867	822/727	8d@6"/12" , 8d@6"/12" at gable end	-38	840/762	822/727	8d@6"/12" , 8d@6"/12" at gable end	-38
	C	1376/1089	1034/919	8d@6"/12" , 8d@6"/12" at gable end	-46	1057/961	1034/919	8d@6"/12" , 8d@6"/12" at gable end	-46
130	B	1327/1049	995/884	8d@6"/9.6" , 8d@6"/9.6" at gable end	-45	1018/925	995/884	8d@6"/12" , 8d@6"/12" at gable end	-45
	C	1646/1309	1244/1109	8d@6"/8" , 8d@6"/8" at gable end	-54	1272/1159	1244/1109	8d@6"/12" , 8d@6"/12" at gable end	-54
140	B	1568/1245	1183/1054	8d@6"/8" , 8d@6"/8" at gable end	-52	1209/1102	1183/1054	8d@6"/12" , 8d@6"/12" at gable end	-52
	C	1938/1547	1472/1315	8d@6"/6.86" , 8d@6"/6.86" at gable end	-63	1503/1373	1472/1315	8d@6"/9.6" , 8d@6"/9.6" at gable end	-63
140 HVHZ	C	1938/1547	1472/1315	8d@6"/6" , 10d@4"/4" at gable end	-63	1503/1373	1472/1315	8d@6"/6" , 10d@4"/4" at gable end	-63
146 HVHZ	C	2123/1698	1616/1446	8d@6"/6" , 10d@4"/4" at gable end	-68	1651/1509	1616/1446	8d@6"/6" , 10d@4"/4" at gable end	-68
150	B	1826/1456	1385/1237	8d@6"/8" , 8d@6"/8" at gable end	-59	1415/1292	1385/1237	8d@6"/12" , 8d@6"/12" at gable end	-59
150	C	2251/1802	1716/1537	8d@6"/6.86" , 8d@6"/6.86" at gable end	-72	1752/1603	1716/1537	8d@6"/9.6" , 8d@6"/9.6" at gable end	-72

[1] All nails are common nails unless noted otherwise

[2] Partially-enclosed designs are not applicable to wind speeds less than 120 mph

Table D-6. Design parameters for model building 1304G/1307G computed using FBC 2006.

Gable Roof Design Values for Building 1304G/1307G in 2006[2]									
Wind Speed	Exp.	FBC Enclosed (Design) 4:12 Roof				FBC Enclosed (Design) 7:12 Roof			
		Design Strap C&C corner / interior (lbf)	Design Strap MWFRS corner / interior (lbf)	Roof Nail Spacing	Window Design pressure (psf)	Design Strap C&C corner / interior (lbf)	Design Strap MWFRS corner / interior (lbf)	Roof Nail Spacing	Window Design pressure (psf)
100	B	524/341	346/280	8d@ 6"/6"	-21	360/305	280/280	8d@ 6"/6"	-21
	C	673/451	451/378	8d@ 6"/6"	-25	473/407	378/378	8d@ 6"/6"	-25
110	B	672/451	457/377	8d[5,6]@ 6"/6"[4]	-25	473/407	377/377	8d[5,6]@ 6"/6"[4]	-25
	C	852/584	592/495	8d[5,6]@ 6"/6"	-30	611/531	495/495	8d[5,6]@ 6"/6"	-30
120	B	834/571	578/483	8d[5,6]@ 6"/6"[4]	-30	597/518	483/483	8d[5,6]@ 6"/6"[4]	-30
	C	1048/729	738/623	8d[5]@ 6"/6"	-36	762/666	623/623	8d[5]@ 6"/6"	-36
130	B	1010/701	710/599	8d[5]@ 6"/6"[4]	-35	732/639	599/599	8d[5]@ 6"/6"[4]	-35
130	C	1262/887	898/763	8d[5]@ 6"/6"	-42	925/813	763/763	8d[5]@ 6"/6"[4]	-42
140	B	1200/842	851/723	8d[5]@ 6"/6"[4]	-41	878/770	723/723	8d[5]@ 6"/6"[4]	-41
	C	1492/1058	1070/914	8d[5]@ 6"/6"	-49	1101/971	914/914	8d[5]@ 6"/6"	-49
140 HVHZ	C	1492/1058	1070/914	8d[1,3,5]@ 6"/6"	-49	1101/971	914/914	8d[1,3,5]@ 6"/6"	-49
146 HVHZ	C	1639/1167	1179/1009	8d[1,3,5]@ 6"/6"	-53	1214/1072	1009/1009	8d[1,3,5]@ 6"/6"	-53
150	B	1404/993	1004/856	8d[5]@ 6"/6"	-47	1034/911	856/856	8d[5]@ 6"/6"	-47
150	C	1740/1241	1255/1075	8d[5]@ 6"/6"	-56	1292/1142	1075/1075	8d[5]@ 6"/6"	-56

[1] Ring shank

[2] All nails are common nails unless noted otherwise

[3] Ring shank nails @4" at gable ends or 10d nails @4" at gable ends

[4] 4"/4" Spacing for component and cladding at edge strip in zone 3 according to FBC, *Building*

[5] FBC *Residential* ring shank with 0.113 inch nominal shank diam., 0.012 ring diam. over shank diam., 16-20 rings per inch, 0.280 in full round

[6] FBC *Residential* allows 6"/12" in zone 1 and 2

Table D-7. Wall design parameters for model building 1304G/1307G computed using FBC 2001 (enclosed design)

Gable Roof Design Values for Building 1304G/1307G in 2001					
Wind Speed	Exp.	FBC Enclosed (Design) 4:12 Roof		FBC Enclosed (Design) 7:12 Roof	
		Wood Wall Framing Size and Spacing[1]	Masonry Wall Vertical Reinforcement Spacing (ft)	Wood Wall Framing Size and Spacing[1]	Masonry Wall Vertical Reinforcement Spacing (ft)
100	B	2x4 @ 16"	10'-0"	2x4 @ 16"	10'-0"
	C	2x4 @ 16"	9'-4"	2x4 @ 16"	9'-4"
110	B	2x4 @ 16"	9'-4"	2x4 @ 16"	9'-4"
	C	2x4 @ 16"	8'-8"	2x4 @ 16"	8'-8"
120	B	2x4 @ 16"	8'-8"	2x4 @ 16"	8'-8"
	C	2x4 @ 16"	7'-4"	2x4 @ 16"	7'-4"
130	B	2x4 @ 16"	8'-0"	2x4 @ 16"	8'-0"
	C	2x4 @ 16"	7'-4"	2x4 @ 16"	7'-4"
140	B	2x4 @ 16"	7'-4"	2x4 @ 16"	7'-4"
	C	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
140 HVHZ	C	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
146 HVHZ	C	2x4 @ 16"	6'-0"	2x4 @ 16"	6'-0"
150	B	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
150	C	2x4 @ 16"	6'-0"	2x4 @ 16"	6'-0"

[1] Wood Species of wood wall: Southern Pine No. 2 Standard, 8ft wall height

Table D-8. Wall design parameters for model building 1304G/1307G computed using FBC 2001 (enclosed design)

Gable Roof Design Values for Building 1304G/1307G in 2001					
Wind Speed	Exp.	FBC Partially Enclosed (Design) 4:12 Roof		FBC Partially Enclosed (Design) 7:12 Roof	
		Wood Wall Framing Size and Spacing[1]	Masonry Wall Vertical Reinforcement Spacing (ft)	Wood Wall Framing Size and Spacing[1]	Masonry Wall Vertical Reinforcement Spacing (ft)
100	B	2x4 @ 16"	N/A	N/A	N/A
	C	2x4 @ 16"	N/A	N/A	N/A
110	B	2x4 @ 16"	N/A	N/A	N/A
	C	2x4 @ 16"	N/A	N/A	N/A
120	B	2x4 @ 16"	7'-4"	2x4 @ 16"	7'-4"
	C	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
130	B	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
	C	2x4 @ 16"	6'-0"	2x4 @ 16"	6'-0"
140	B	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
	C	2x4 @ 16"	6'-0"	2x4 @ 16"	6'-0"
140 HVHZ	C	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
146 HVHZ	C	2x4 @ 16"	5'-4"	2x4 @ 16"	5'-4"
150	B	2x4 @ 16"	6'-0"	2x4 @ 16"	6'-0"
150	C	2x4 @ 16"	5'-4"	2x4 @ 16"	5'-4"

[1] Wood Species of wood wall: Southern Pine No. 2 Standard, 8ft wall height

Table D-9. Wall design parameters for model building 1304G/1307G computed using FBC 2006.

Gable Roof Design Values for Building 1304G/1307G in 2006					
Wind Speed	Exp.	FBC Enclosed (Design) 4:12 Roof		FBC Enclosed (Design) 7:12 Roof	
		Wood Wall Framing Size and Spacing[1]	Masonry Wall Vertical Reinforcement Spacing (ft)	Wood Wall Framing Size and Spacing[1]	Masonry Wall Vertical Reinforcement Spacing (ft)
100	B	2x4 @ 16"	10'-0"	2x4 @ 16"	10'-0"
	C	2x4 @ 16"	9'-4"	2x4 @ 16"	9'-4"
110	B	2x4 @ 16"	9'-4"	2x4 @ 16"	9'-4"
	C	2x4 @ 16"	8'-8"	2x4 @ 16"	8'-8"
120	B	2x4 @ 16"	8'-8"	2x4 @ 16"	8'-8"
	C	2x4 @ 16"	7'-4"	2x4 @ 16"	7'-4"
130	B	2x4 @ 16"	8'-0"	2x4 @ 16"	8'-0"
130	C	2x4 @ 16"	7'-4"	2x4 @ 16"	7'-4"
140	B	2x4 @ 16"	7'-4"	2x4 @ 16"	7'-4"
	C	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
140 HVHZ	C	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
146 HVHZ	C	2x4 @ 16"	6'-0"	2x4 @ 16"	6'-0"
150	B	2x4 @ 16"	6'-8"	2x4 @ 16"	6'-8"
150	C	2x4 @ 16"	6'-0"	2x4 @ 16"	6'-0"

[1] Wood Species of wood wall: Southern Pine No. 2 Standard, 8ft wall height

Table D-10. Design of Building 1307G. 7:12 Gable Roof 27°< θ <45° (According to FBC 2004 with Supplements up to 2007 & ASCE 7-02)

Input Parameters

$in0 := (130 \quad C \quad Enclosed)$

Design Wind Speed = 130 mph
Exposure C
Enclosed (assumed since fenestrations are protected)
Assume ASD design

Variables for Exposure

$$\begin{pmatrix} A \\ B \\ C \\ D \end{pmatrix} \equiv \begin{pmatrix} 0 \\ 1 \\ 2 \\ 3 \end{pmatrix}$$

Variables for Enclosed/Part Encl.

$Enclosed \equiv 0$

$PartEnclosed \equiv 1$

Note Exposure A is no longer used

For High velocity regions in Florida (Dade & Broward county)
Exposure shall be C, with design wind speeds of
140 and 146 mph respectively.

Design Parameters

$V := |in0^{\langle 0 \rangle}| \cdot mph$ $\quad V = 130mph$

$Exp := |in0^{\langle 1 \rangle}|$ $\quad Case := 1$

Case 1 = C&C and MWFRS for low rise bldgs

$IntPressure := |in0^{\langle 2 \rangle}|$

$\underline{I} := 1.0$

Importance for Class II Building

Geometry of Building: Aubuchon homes

$h := 13 \cdot ft + 8.5in$ Average ht of building (mean roof height)

$\theta := atan\left(\frac{7}{12}\right)$ $\quad \underline{\theta} = 30.26deg$ roof slope

$o := 0 \cdot ft$ overhang width

$o_g := 0 \cdot ft$ overhang at "gable" end

$W := 30ft + 2 \cdot o$ dimensions of building

$\underline{L} := 60\underline{ft} + 2 \cdot \underline{o_g}$

$\underline{\Delta} := 2\underline{ft}$ Truss spacing

Roof cover: Shingle

$h_{wall} := 9 \cdot ft$ Height of Wall

Total number of Straps in the roof

Dead load of roof

$DL_{roof} := 10 \cdot psf$ Hip roof, shingle, trusses, underlayment (FBC 2004 t2304.7(1))

Dead load of roof is composed of following: Truss/Sheathing (7 psf), plus Tile (10psf) or shingles (3 psf).

$DL_{sheath} := (0.625\,in)\cdot\left(\frac{0.4\,psf}{.125\,in}\right)$ $DL_{sheath} = 2\,psf$ Minimum Roof sheathing thickness as per Table R803.1

$L_{attic} := 30\cdot psf$ FBC Table 1607.1

$L_{floor} := 40\cdot psf$

$L_{roof} := 18\cdot psf$ FBC 1607.11.2.1

$\phi := 0.6$ Fraction of DeadLoad used in combination with Wind Load

$DL_{wall} := \begin{pmatrix} 10 \\ 55 \end{pmatrix}\cdot psf$ Wood Frame wall weight / Masonry Wall Weight

$DL_{misc} := 15\cdot psf$ Miscellaneous: Contents, carpet, cabinets, fixtures)

AREAS: Roof - Gable

Vertical Projected Area: wind perpendicular to ridge

$h_{ridge} := \frac{W}{2}\cdot\tan(\theta)$ $h_{ridge} = 8.75\,ft$

$VPA_{\perp} := h_{ridge}\cdot(L)$ $VPA_{\perp} = 525\,ft^2$

Vertical Projected Area: wind parallel to ridge

$VPA_{\parallel} := 0ft^2$ $VPA_{\parallel} = 0$

Horizontal Projected Area:

$HPA := W\cdot L$ $HPA = 1800\,ft^2$

AREAS: Walls

Vertical Projected Area: wind parallel and perpendicular to ridge - portion of horizontal load transferred directly to foundation

$VPA_{wall\perp} := \frac{h_{wall}}{2}\cdot(L - 2o_g)$ $VPA_{wall_\parallel} := \frac{h_{wall}}{2}\cdot(W - 2\cdot o) + \frac{h_{ridge}\cdot W}{2}$

$VPA_{wall\perp} = 270\,ft^2$ $VPA_{wall_\parallel} = 266.25\,ft^2$

Dynamic Wind Pressure

Exposures = A,B,C,D

Terrain Exposure Constants

$$z_g := \begin{pmatrix} 1500\cdot ft \\ 1200\cdot ft \\ 900\cdot ft \\ 700\cdot ft \end{pmatrix} \quad \underline{\alpha} := \begin{pmatrix} 5.0 \\ 7.0 \\ 9.5 \\ 11.5 \end{pmatrix} \quad h_{min} := \begin{pmatrix} 60 \\ 30 \\ 15 \\ 7 \end{pmatrix} \cdot ft$$

$$h_{min} := \begin{cases} \begin{pmatrix} 100 \\ 30 \\ 15 \\ 15 \end{pmatrix} \cdot ft & \text{if } Case = 1 \\ \begin{pmatrix} 15 \\ 15 \\ 15 \\ 15 \end{pmatrix} \cdot ft & \text{otherwise} \end{cases}$$

$$\underline{K_z}(\underline{h}) := \begin{cases} 2.01 \cdot \left(\frac{15\cdot ft}{z_{g_{Exp}}} \right)^{\frac{2}{\alpha_{Exp}}} & \text{if } \underline{h} < 15\cdot \underline{ft} \\ 2.01 \cdot \left(\frac{h_{min_{Exp}}}{z_{g_{Exp}}} \right)^{\frac{2}{\alpha_{Exp}}} & \text{if } \underline{h} < h_{min_{Exp}} \\ 2.01 \cdot \left(\frac{\underline{h}}{z_{g_{Exp}}} \right)^{\frac{2}{\alpha_{Exp}}} & \text{otherwise} \end{cases}$$

$Exp = 2$

$K_z(h) = 0.85$

$\underline{K_{zt}} := 1.0$ No topographic speedup

$\underline{K_d} := 0.85$ Directionality factor (0.85 used when doing combination loads - with dead load)

Internal Pressure coefficient

$$q_h := .00256 \frac{slug}{2.15111 ft^3} \cdot K_z(h) \cdot K_{zt} \cdot K_d \cdot V^2 \cdot I$$

$q_h = 31.22 psf$ Dynamic Wind Pressure

internal pressure range variable

$$GC_{pi} := \begin{cases} \begin{pmatrix} -0.18 \\ 0.18 \end{pmatrix} & \text{if } IntPressure = Enclosed \\ \begin{pmatrix} -0.55 \\ 0.55 \end{pmatrix} & \text{if } IntPressure = PartEnclosed \\ \begin{pmatrix} -20 \\ 20 \end{pmatrix} & \text{otherwise} \end{cases}$$

$$GC_{pi} = \begin{pmatrix} -0.18 \\ 0.18 \end{pmatrix}$$

$posneg := 0..1$

◄—— Dummy value in Case Int Pressure is invalid

Gust Factor:

Terrain Exposure Constants from Table 6-2

$$l := \begin{pmatrix} 320 \\ 500 \\ 650 \end{pmatrix} \cdot ft \qquad \varepsilon := \begin{pmatrix} \frac{1}{3} \\ \frac{1}{5} \\ \frac{1}{8} \end{pmatrix} \qquad c := \begin{pmatrix} 0.3 \\ 0.2 \\ 0.15 \end{pmatrix} \qquad z_{min} := \begin{pmatrix} 30 \\ 15 \\ 7 \end{pmatrix} \cdot ft$$

$$z_{bar} := \begin{pmatrix} 0.6 \cdot h \\ z_{min_{Exp}} \end{pmatrix} \qquad z_e := \max(z_{bar}) \qquad z_{bar} = \begin{pmatrix} 8.22 \\ 7 \end{pmatrix} ft$$

Equivalent height of structure

$$I_z := c_{Exp} \cdot \left(\frac{33 \cdot ft}{z_e} \right)^{\frac{1}{6}} \qquad I_z = 0.19$$

Turbulence Intensity (eqn 6-5)

$$L_z := l_{Exp} \cdot \left(\frac{z_e}{33 \cdot ft} \right)^{\varepsilon_{Exp}} \qquad L_z = 546.38\,ft$$

Integral Length Scale of Turbulence (Eqn 6-5)

$$Q := \sqrt{\frac{1}{1 + 0.63 \cdot \left(\frac{W + h}{L_z} \right)^{0.63}}} \qquad Q = 0.94$$

Background Response (Eqn 6-6)

Use W rather than L since it leads to a higher Q value

$g_Q := 3.4$ $\quad g_v := 3.4$

$$G := 0.925 \left(\frac{1 + 1.7 \cdot g_Q \cdot I_z \cdot Q}{1 + 1.7 \cdot g_v \cdot I_z} \right) \qquad G = 0.9$$

Gust Factor (Eqn 6-4)

External Pressure Coefficients: Figure 6-5B

Limits of External Pressure Coefficients for each Zone in C&C loads
(first row neg coefficients, second row positive coefficents). Based on the Values in the Chart, prepare equations that interpolate in-between areas.

Interpolate equations between 10 and 100 square feet

ASCE7-02: Figure 6-11D Gable/Hip Roofs 27 deg <θ< 45 deg for Component and Cladding method

For regions 1-3 for Figure 6-11D

$$GCp_1 := \begin{pmatrix} -1.0 & -0.8 \\ 0.9 & 0.8 \end{pmatrix} \qquad \underline{Alim}_1 := (10 \;\; 100)\cdot ft^2$$

$$GCp_2 := \begin{pmatrix} -1.2 & -1.0 \\ 0.9 & 0.8 \end{pmatrix} \qquad \underline{Alim}_2 := (10 \;\; 100)\cdot ft^2$$

$$GCp_3 := \begin{pmatrix} -1.2 & -1.0 \\ 0.9 & 0.8 \end{pmatrix} \qquad \underline{Alim}_3 := (10 \;\; 100)\cdot ft^2$$

For regions 4-5 (walls) for Figure 6-11A

Interpolation coefficients between 10 and 500 square feet. First Column is 10ft^2, second is 500ft^2

ASCE7-02: Figure 6-11A

$$GCp_4 := \begin{pmatrix} -1.1 & -0.8 \\ 1.0 & 0.7 \end{pmatrix} \qquad \underline{Alim}_4 := (10 \;\; 500)\cdot ft^2$$

$$GCp_5 := \begin{pmatrix} -1.4 & -0.8 \\ 1.0 & 0.7 \end{pmatrix} \qquad \underline{Alim}_5 := (10 \;\; 500)\cdot ft^2$$

overhang coefficients

$$GCp_6 := \begin{pmatrix} -2.0 & -1.8 \\ 0 & 0 \end{pmatrix} \quad \text{Zone 2} \qquad \underline{Alim}_6 := (10 \;\; 100)\cdot ft^2$$

$$GCp_7 := \begin{pmatrix} -2.0 & -1.8 \\ 0 & 0 \end{pmatrix} \quad \text{Zone 3} \qquad \underline{Alim}_7 := (10 \;\; 100)\cdot ft^2$$

$$slope_{GCp}(Zone) := \frac{\left| GCp_{Zone}^{\langle 1 \rangle} \right| - \left| GCp_{Zone}^{\langle 0 \rangle} \right|}{\log\left[\frac{\left|\left| Alim_{Zone}^{\langle 1 \rangle} \right|\right|}{ft^2}\right] - \log\left[\frac{\left|\left| Alim_{Zone}^{\langle 0 \rangle} \right|\right|}{ft^2}\right]}$$

$$GC_p(Area, Zone) := \begin{cases} \left| GCp_{Zone}^{\langle 0 \rangle} \right| & \text{if } Area < \left| \left| Alim_{Zone}^{\langle 0 \rangle} \right| \right| \\ \left| GCp_{Zone}^{\langle 1 \rangle} \right| & \text{if } Area > \left| \left| Alim_{Zone}^{\langle 1 \rangle} \right| \right| \\ slope_{GCp}(Zone) \cdot \left[\log\left(\frac{Area}{ft^2} \right) - \log\left[\frac{\left|\left| Alim_{Zone}^{\langle 0 \rangle} \right|\right|}{ft^2} \right] \right] + \left| GCp_{Zone}^{\langle 0 \rangle} \right| & \text{otherwise} \end{cases}$$

For Example:

$$GC_p\left(10\cdot ft^2, 4\right) = \begin{pmatrix} -1.1 \\ 1 \end{pmatrix} \qquad GC_p\left(200\cdot ft^2, 5\right) = \begin{pmatrix} -0.94 \\ 0.77 \end{pmatrix} \qquad GC_p\left(100\cdot ft^2, 1\right) = \begin{pmatrix} -0.8 \\ 0.8 \end{pmatrix} \qquad GC_p\left(10\cdot ft^2, 6\right) = \begin{pmatrix} -2 \\ 0 \end{pmatrix}$$

$$GC_p\left(200\cdot ft^2, 4\right) = \begin{pmatrix} -0.87 \\ 0.77 \end{pmatrix}$$

Window Design Pressure

The following input table was imported from an excel sheet that had a list of fens for this building. Each column represents the width, height, area, zone on the wall of interest, and fraction of Fen in zone 5 of each fen respectively.

Width Height Area Zone Fraction := 4

Fen :=

	0	1	2	3	4
0	5	3	15	4	1
1	5	3	15	4	1
2	5	3	15	4	1
3	5	3	15	4	1
4	5	3	15	4	1
5	3	6.7	20.1	4	1
6	3.33	5	16.65	4	1
7	3.33	5	16.65	4	1
8	3.33	5	16.65	4	1
9	20	7	140	45	0.1
10	5	3	15	45	0.4
11	5	3	15	4	1
12	3	6.7	20.1	4	0.22
13	3.5	6.7	23.45	4	1
14	3.5	6.7	23.45	4	1
15	6	4	24	4	1
16	5	3	15	4	1

When Zone = 45, Fraction represents portion of fen in Zone 5.

Zone := 3 Area := 2 rows(Fen) = 20 j := 0.. rows(Fen) − 1

$$DP^{\langle j \rangle} := \begin{cases} q_h \cdot \left(GC_p\left(\left| \overrightarrow{Fen^{\langle Area \rangle}_j \cdot ft^2} \right|, \overrightarrow{Fen^{\langle Zone \rangle}_j} \right) + GC_{pi} \right) & \text{if } Fen^{\langle Zone \rangle}_j \neq 45 \\ q_h \cdot \left(GC_p\left(\left| \overrightarrow{Fen^{\langle Area \rangle}_j \cdot ft^2} \right|, 5 \right) + GC_{pi} \right) \cdot Fen^{\langle Fraction \rangle}_j \ldots & \text{otherwise} \\ + q_h \cdot \left(GC_p\left(\left| \overrightarrow{Fen^{\langle Area \rangle}_j \cdot ft^2} \right|, 4 \right) + GC_{pi} \right) \cdot \left[1 - Fen^{\langle Fraction \rangle}_j \right] \end{cases}$$

DP =

	4	5	6	7	8	9	10	11	12
0	-38.99	-38.29	-38.74	-38.74	-38.74	-33.95	-42.35	-38.99	-38.29
1	35.87	35.17	35.62	35.62	35.62	30.52	35.87	35.87	35.17

psf

Highest Design pressures are: $DP^{\langle 10 \rangle} = \begin{pmatrix} -42.35 \\ 35.87 \end{pmatrix}$ psf

Note: Windows 17-19 are not used

Design of Nailing Pattern for Roof Deck

Tributary area for single fastener: $\underline{Area} := 10 \cdot \underline{ft}^2$

Zone1 Zone 2 Zone 3

$GC_p(Area, 1) = \begin{pmatrix} -1 \\ 0.9 \end{pmatrix}$ $GC_p(Area, 2) = \begin{pmatrix} -1.2 \\ 0.9 \end{pmatrix}$ $GC_p(Area, 3) = \begin{pmatrix} -1.2 \\ 0.9 \end{pmatrix}$

Design load: Zone2

$p_{singleZ2} := q_h \cdot \left| GC_p(Area, 2) + GC_{pi} \right|$ $p_{singleZ2} = \begin{pmatrix} -43.08 \\ 33.71 \end{pmatrix} psf$ $q_h = 31.22 psf$

$p_{singleZ2_0} = -43.08 psf$

Design load: Zone 3

$p_{singleZ3} := q_h \cdot \left| GC_p(Area, 3) + GC_{pi} \right|$ $p_{singleZ3} = \begin{pmatrix} -43.08 \\ 33.71 \end{pmatrix} psf$ $q_h = 31.22 psf$

$p_{singleZ3_0} = -43.08 psf$

Tributary area for single sheet of plywood fastener: $\underline{Area} := 32 \cdot \underline{ft}^2$

One 4x8ft sheet of plywood/OSB = 32 FT tributary area

Zone1 Zone 2 Zone 3

$GC_p(Area, 1) = \begin{pmatrix} -0.9 \\ 0.85 \end{pmatrix}$ $GC_p(Area, 2) = \begin{pmatrix} -1.1 \\ 0.85 \end{pmatrix}$ $GC_p(Area, 3) = \begin{pmatrix} -1.1 \\ 0.85 \end{pmatrix}$

$p_{panel} := q_h \cdot \left| GC_p(Area, 2) + GC_{pi} \right|$ $p_{panel} = \begin{pmatrix} -39.93 \\ 32.14 \end{pmatrix} psf$

Resistance of single 8d Nail

Load Case : Wind + 60% of dead load

$q_r := 41 \cdot \frac{lbf}{in}$ 8d common nail, NDS 2005, page 70, diameter 0.131"

$l_{nail} := 2.5 in$ length of nail, 8d

$t := \frac{5}{8} \cdot in$ Plywood thickness = 5/8" from 2322.2.2 for High Velocity zones, See table 2304.7 otherwise Southern Pine SG - 0.55 on page 74, Table 11.3.2A of NDS 2005

$l_p := l_{nail} - t$ $l_p = 1.88 in$ penetration length

$\underline{C_D} := 1.6$ Duration factor for short term loads - wind = 10 minutes

$\underline{C_m} := 1.0$ Condition Factor = assume that wood moisture content at time of construction is same as long term value

$R_{shank} := 2 \cdot 0.92$ Use a factor of 2 minus a 8 percent reduction for galvanized ring shank nails for pull out

nail diam

$R_{nail} := q_r \cdot l_p \cdot C_D \cdot C_m \cdot R_{shank}$ $R_{nail} = 226.32\,lbf$ $d_{nail} := 0.131in$

Check Nail Resitance vs Applied Loads:

$P_{width} := 4ft$ Panel width

Minimum spacing of nails due to uplift ONLY in zone 2, interior of panel itself

$$s_{zone2_int} := \frac{R_{nail}}{\left| -1\, p_{singleZ2_0} \right| \cdot \underline{\Delta}} \qquad s_{zone2_int} = 31.52in$$

Minimum spacing of nails due to uplift ONLY in zone 3 interior of panel itself

$$s_{zone3_int} := \frac{R_{nail}}{\left| -1\, p_{singleZ3_0} \right| \cdot \underline{\Delta}} \qquad s_{zone2_int} = 31.52in$$

Check Panel Resistance vs Applied Loads for a 1ft Strip of Sheathing:

Check bending in zone 3

$$M_{sheath} := \underline{\Delta}^2 \cdot \frac{p_{singleZ3_0} \cdot 1ft}{10}$$

Check flexure of the panels, 5 ply plywood, 40/20 rated as per FBC table 2304.6 for 100mph+ winds. Formula for moment over 3 continuous supports

$\left| M_{sheath} \right| = 17.23\,lbf \cdot ft$

$I_{panel} := \frac{1}{12} \cdot 1ft \cdot t^3$ $I_{panel} = 0.24in^4$

$c_{panel} := \frac{t}{2}$

$$P_{stress} := c_{panel} \cdot \frac{\left| M_{sheath} \right|}{I_{panel}}$$

$P_{stress} = 264.68 \frac{lbf}{in^2}$

$Panel_{stiff} := 250000lbf \cdot \frac{in^2}{ft}$

$Panel_{strength} := 750lbf \cdot \frac{in}{ft}$

Values from NDS 2005 manual table M9.2-1, bending parallel to axis

$E_{panel} := \frac{Panel_{stiff} \cdot \underline{\Delta}}{I_{panel}}$ $E_{panel} = 2.05 \times 10^6 psi$

$C_s := 1.0$ page 220 in NDS 2005 commentary

$C_t := 1.0$

$C_m := 1.0$

$C_D = 1.6$ for wind

$\underline{\sigma}_{nail} := 100000psi$ Allowable yield stress of nail according to FBC 2303.6

$Status_{sheath} := Panel_{strength} \cdot \Delta \cdot C_s \cdot C_t \cdot C_m > |M_{sheath}|$ PASS = 1, FAIL = 0 $Status_{sheath} =$ 1

Check Shear in the panel

Example from NDS page 92 in example manual 2005

$Fs_ibQ := 265 \frac{lbf}{ft}$ allowable load from the M.NDS page 65 for rolling shear

$Panel_{shear} := |\Delta - 1.5in| \cdot p_{singleZ3_0} \cdot 1ft \cdot 0.6$ $Panel_{shear} = -48.46lbf$ assume a 2x4 for truss construction

$Status_{sheathshear} := Fs_ibQ \cdot 1ft > |Panel_{shear} \cdot C_s \cdot C_t \cdot C_m|$ PASS = 1, FAIL = 0 $Status_{sheathshear} = 1$

Check roof assembly using component and cladding method in ASCE 02 (Figure 6-11C)

$l_{chord} := 3ft$ Length of top chord member of truss. Assume simple span 3' segment of roof truss. Member is assumed to be pinned to adjoining similar member

$a := \min\begin{pmatrix} 0.1 \cdot W \\ 0.1 \cdot L \\ 0.4 \cdot h \end{pmatrix}$ $a := \max\begin{pmatrix} a \\ 0.04 \cdot W \\ 0.04 \cdot L \\ 3 \cdot ft \end{pmatrix}$ $l_{chord} = 3\ ft$ $a = 3ft$

$Stud_{area} := 1.5 \cdot 3.5in^2$ $Stud_{area} = 5.25in^2$

$Stud_d := 3.5in$ $stud_w := 1.5in$

Find maximum shear force in the top chord, assumed to be near the corner truss in zone 3 (conservative)

$p_2 := q_h \cdot |GC_p(Area, 2) + GC_{pi}|$ $p_3 := q_h \cdot |GC_p(Area, 3) + GC_{pi}|$ $p_{2_0} = -39.93psf$

$p_{3_0} = -39.93psf$

Moment at edge strip zone 3

$M_{max} := \Delta \cdot l_{chord}^2 \cdot \frac{p_{3_0}}{8}$ $M_{max} = -89.83lbf \cdot ft$

Lumber Design Values from Table 4B, NDS-S 2005

Bending stress, allowable
Tension Parallel to grain, allowable
Shear parallel to grain, allowable
Compression Perpendicular to grain
Compression Parallel to grain
Modulus of Elasticity

Species and Grade:
Southern Pine, No 2.

Note for high velocity regions minimum quality is 2, from section 2317.1 from the FBC

Design top chord of truss as a composite section

$F_b := 1500\,psi$

$F_t := 825\,psi$

$F_v := 175\,psi$

$Fcp := 565\,psi$

$F_c := 1650\,psi$

$E := 1600000\,psi$

$n := \frac{E_{panel}}{E}$ $n = 1.28$ $t = 0.63in$

$Sheath_{area} := |\Delta| \cdot t$ $Sheath_{area} = 15\,in^2$

$I_{xx_sheath} := \frac{|\Delta| \cdot t^3}{12}$ $I_{xx_sheath} = 0.49\,in^4$ about it's centroid

$Stud_{.area} := 1.5 \cdot 3.5\,in^2$ $Stud_{area} = 5.25\,in^2$

Try using 2x4 in the truss

$Stud_{d.} := 3.5in$ $stud_{w.} := 1.5in$

distance of centroid of composite section

$$y_c := \frac{Stud_{area} \cdot \frac{Stud_d}{2} + n \cdot Sheath_{area} \cdot \left(Stud_d + \frac{t}{2}\right)}{Stud_{area} + n \cdot Sheath_{area}}$$

$$I_{xx_stud} := \frac{|\Delta| \cdot Stud_d^3}{12}$$

$y_c = 3.37in$

Net Moment of Inertia about centroid axis:

$$I_{xx} := I_{xx_stud} + Stud_{area}\cdot\left(y_c - \frac{Stud_d}{2}\right)^2 \ldots + I_{xx_sheath}\cdot n + Sheath_{area}\cdot n\cdot\left(Stud_d + \frac{t}{2} - y_c\right)^2 \qquad I_{xx} = 103.91in^4$$

Check Flexure of the 2x4

$$\sigma_{tchord} := M_{max}\cdot\frac{y_c}{I_{xx}} \qquad \sigma_{tchord} = -34.96psi$$

$$Status_{truss} := F_b\cdot C_s\cdot C_t\cdot C_m > \left|\sigma_{tchord}\right| \qquad \text{PASS = 1, FAIL = 0} \qquad Status_{truss} = 1$$

Check transverse shear in the nail at gable end in zone 2 and 3

$$V_{gable} := q_h\cdot\left|GC_p(Area, 5) + GC_{pi}\right|\cdot\left|a^2\cdot\tan\left|\underline{\theta}\right|\right| + q_h\cdot\left|GC_p(Area, 4) + GC_{pi}\right|\cdot\left(h_{ridge}\cdot\frac{W}{2} - a^2\cdot\tan\left|\underline{\theta}\right|\right)$$

$V_{gable_0} = -4913.57lbf$ total load acting on the triangle portion of the gable end

$$Vperim := \frac{V_{gable_0}}{W + 2\cdot\left|h_{ridge}\right| + 2\cdot\left[h_{ridge}^2 + \left(\frac{W}{2}\right)^2\right]^{0.5}}$$

perimeter around the triangular portion of the gable assume that the base of the triangle transfers load to the stud wall

$Vperim = -59.75\frac{lbf}{ft}$ Note however, that support is due to nails in the sheathing and stud blocking

$\tau_{nailzone2gable} := Vperim$ $\tau_{nailzone2gable} = -59.75\frac{1}{ft}lbf$

$\tau_{nailzone3gable} := Vperim$ $\tau_{nailzone3gable} = -59.75\frac{1}{ft}lbf$

Calculate resistances to other failure modes for a nail in zone 3 gable end

follow example in NDS page 153 for a nail splice connection for single shear,
and see NDS 11.3 for lateral load design values

$l_m := l_p$ $l_m = 1.88in$ penetration into main member (truss2 x 4)

$l_s := t$ $l_s = 0.63in$

$Fes_{bply} := 3350psi$ allowable bearing force on the plywood 5 ply Table 11.3.2.B

$F_{em2x4} := 5550psi$ allowable bearing force on the southern pine table 11.3.2 for sg =0.55

$R_e := \frac{F_{em2x4}}{Fes_{bply}}$ $R_e = 1.66$ Ratio of bearing between ply wood and 2x4

$F_{yb} := \sigma_{nail}$ Yield bending strength of the nail as per FBC

$R_t := \frac{l_m}{l_s}$ $R_t = 3$ $l_p = 1.88in$

$K_\theta := 1 + 0.25 \cdot \left(\frac{90}{90}\right)$ $K_\theta = 1.25$ Table 11.3.1B accounts for uplift force

$K_D := \begin{cases} 2.2 & \text{if } d_{nail} \le 0.17in \\ 10 \cdot \frac{d_{nail}}{in} + 0.5 & \text{if } 0.17in < d_{nail} \le 0.25in \end{cases}$ Table 11.3.1B

$K_D = 2.2$

$k_1 := \frac{\left[R_e + 2 \cdot R_e^2 \cdot \left(1 + R_t + R_t^2\right) + R_t^2 \cdot R_e^3\right]^{0.5} - R_e \cdot (1 + R_t)}{1 + R_e}$ $k_1 = 1.52$

$k_2 := -1 + \left[2 \cdot (1 + R_e) + \frac{2 \cdot F_{yb} \cdot (1 + 2 \cdot R_e) \cdot d_{nail}^2}{3 \cdot F_{em2x4} \cdot l_m^2}\right]^{0.5}$ $k_2 = 1.36$

$k_3 := -1 + \left[2 \cdot \left(\frac{1 + R_e}{R_e}\right) + \frac{2 \cdot F_{yb} \cdot (2 + R_e) \cdot d_{nail}^2}{3 \cdot F_{em2x4} \cdot l_s^2}\right]^{0.5}$ $k_3 = 1.27$

Check Yield modes for the nail as per Table 11.3.1A

$I_m := \frac{d_{nail} \cdot l_m \cdot F_{em2x4}}{K_D}$ $I_m = 619.64lbf$

$I_s := \frac{d_{nail} \cdot l_s \cdot F_{em2x4}}{K_D}$ $I_s = 206.55lbf$

$II := \frac{k_1 \cdot d_{nail} \cdot l_s \cdot Fes_{bply}}{K_D}$ $II = 189.94lbf$

$III_m := \frac{k_2 \cdot d_{nail} \cdot l_m \cdot F_{em2x4}}{(1 + 2 \cdot R_e) \cdot K_D}$ $III_m = 195.27lbf$

$III_s := \frac{k_3 \cdot d_{nail} \cdot l_s \cdot F_{em2x4}}{(2 + R_e) \cdot K_D}$ $III_s = 71.54lbf$

$IV := \frac{d_{nail}^2}{K_D} \cdot \left[\frac{2 \cdot F_{em2x4} \cdot F_{yb}}{3 \cdot (1 + R_e)}\right]^{0.5}$ $IV = 92.06lbf$

Spacing of nails due only to uplift, no shear

$s_{zone2_int} = 31.52in$

$NumNail_{z2int} := ceil\left(\frac{48in}{s_{zone2_int}}\right)$ $NumNail_{z2int} = 2$ $S_{EvenZone2int} := 48\frac{in}{NumNail_{z2int}}$

$s_{zone3_int} = 31.52in$ $S_{EvenZone2int} = 24in$

$NumNail_{z3int} := ceil\left(\frac{48in}{s_{zone3_int}}\right)$ $NumNail_{z3int} = 2$ $S_{EvenZone3int} := 48\frac{in}{NumNail_{z3int}}$

$S_{EvenZone3int} = 24in$

Check spacing of nails in zone2 and 3 due to shear at gable end

$$S_{zone2gab} := \frac{\min\left(C_D \cdot \min\left(I_m, I_s, II, III_m, III_s, IV\right)\right)}{-\tau_{nailzone2gable} \cdot S_{EvenZone2int}} \qquad S_{zone2gab} = 0.96$$

$$S_{zone3gab} := \frac{\min\left(C_D \cdot \min\left(I_m, I_s, II, III_m, III_s, IV\right)\right)}{-\tau_{nailzone3gable} \cdot S_{EvenZone3int}} \qquad S_{zone3gab} = 0.96$$

$$S_{zone2gable} := \begin{cases} S_{EvenZone2int} & \text{if } S_{zone2gab} \geq 1 \\ 48\frac{in}{ceil\left(\frac{48in}{S_{zone2gab} \cdot S_{EvenZone2int}}\right)} & \text{otherwise} \end{cases} \qquad S_{zone2gable} = 16in$$

$$S_{zone3gable} := \begin{cases} S_{EvenZone3int} & \text{if } S_{zone3gab} \geq 1 \\ 48\frac{in}{ceil\left(\frac{48in}{S_{zone3gab} \cdot S_{EvenZone3int}}\right)} & \text{otherwise} \end{cases} \qquad S_{zone3gable} = 16in$$

Use Minimum Spacing of 8d ring shank nails at 6"/12"

Roof Strap Design for Uplift: Design a Center Truss

Several methods of calculating the uplift on the truss have been explored here.
The ARA roof-strap model simulates failure of the entire roof assembly as a whole, and not any one specific truss connection. Therefore, strap size in model should be based on strap representative of the majority of the connections, and therefore is based on section at middle of structure.

1. Analyze the center and corner truss by the Method 2 of ASCE-02 (Component and Cladding)
2. Analyze the roof system as a whole with Method 2 of ASCE-02 and divide by the number of straps to get an average strap force value
3. As above, but examine a center truss in particular

In addition, for comparison to prescriptive documents, the corner truss load has also be considered by two methods from ASCE-02: Method 2 C&C loads and Method 3 MWFRS loads.

Note that Table 2308.10.1 in FBC for minimum loads cannot be used since wind speed and span are not listed. These values have to be computed directly

Edge zone

$a := \min\left(\begin{pmatrix} 0.1\cdot W \\ 0.1\cdot L \\ 0.4\cdot h \end{pmatrix}\right)$ $a := \max\left(\begin{pmatrix} a \\ 0.04\cdot W \\ 0.04\cdot L \\ 3\cdot ft \end{pmatrix}\right)$ $\underline{a} = 3\,\underline{ft}$

$\underline{l_r} := \frac{\underline{W}}{2\cdot\underline{\cos(\theta)}}$ $\underline{l_r} = 17.37\,\underline{ft}$ length of top chord of truss

$a_{\underline{\theta}} := \frac{a}{\cos(\underline{\theta})}$ length of edge zones along roof slope - assume that a in ASCE7 figures are widths in plan.

1. Method 2 of ASCE-02 Components and Cladding for a Center Truss

Effective wind area of a truss equals maximum of actual area and span times 1/3 span length

External Gust Factors

$A_{eff} := \begin{pmatrix} W\cdot\underline{\Delta} \\ W\cdot\frac{W}{3} \end{pmatrix}$ $A_{eff} = \begin{pmatrix} 60 \\ 300 \end{pmatrix} ft^2$ $A_{eff} := \max(A_{eff})$ $A_{eff} = 300\,ft^2$

$GC_p(A_{eff}, 1) = \begin{pmatrix} -0.8 \\ 0.8 \end{pmatrix}$ $GC_p(A_{eff}, 2) = \begin{pmatrix} -1 \\ 0.8 \end{pmatrix}$ $GC_p(A_{eff}, 3) = \begin{pmatrix} -1 \\ 0.8 \end{pmatrix}$

$k := 1..3$ $p_k := \left(GC_p(A_{eff}, k)_0 + GC_{pi_0}\right)\cdot q_h$

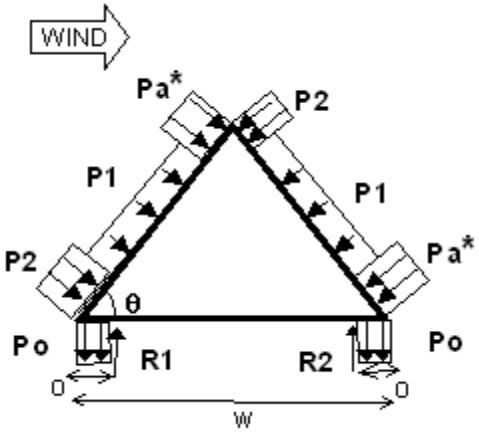
$p = \begin{pmatrix} 0 \\ -30.59 \\ -36.84 \\ -36.84 \end{pmatrix} psf$ Design Pressures for Zones 1, 2, and 3

$p_{int} := \left(GC_{pi_0}\right)\cdot q_h$

Overhang pressures $p_o := \left| GC_p\left| A_{eff}, 6 \right|_0 \right| \cdot q_h$ $GC_p\left| A_{eff}, 6 \right| = \begin{pmatrix} -1.8 \\ 0 \end{pmatrix}$ $p_o = -56.19\,psf$

Analyze the Center Truss by the Method 2 of ASCE-02
(Component and Cladding)

Note that internal pressure has been included in P1,P2 etc.



$p_a := p_2$

Sum Moments: about R2 reaction point

$$R_1 := \frac{1}{W - 2\cdot o}\cdot\left[\begin{array}{l}
p_o\cdot\frac{o}{\cos(\underline{\theta})}\cdot\underline{\Delta}\cdot\cos(\underline{\theta})\cdot\left(W - o - \frac{o}{2}\right) \ldots \\
+ p_2\cdot\left(a_{\underline{\theta}} - \frac{o}{\cos(\underline{\theta})}\right)\cdot\underline{\Delta}\cdot\cos(\underline{\theta})\cdot\left(W - o - \frac{a - o}{2} - o\right) \ldots \\
+ p_2\cdot a_{\underline{\theta}}\cdot\underline{\Delta}\cdot\cos(\underline{\theta})\cdot\left(\frac{W}{2} - o - \frac{a_{\underline{\theta}}}{2}\cdot\cos(\underline{\theta})\right) \ldots \\
+ p_a\cdot a_{\underline{\theta}}\cdot\underline{\Delta}\cdot\cos(\underline{\theta})\cdot\left[W - o - \left(l_r - \frac{a_{\underline{\theta}}}{2}\right)\cdot\cos(\underline{\theta})\right] \ldots \\
+ \left[p_a\cdot\left(a_{\underline{\theta}} - \frac{o}{\cos(\underline{\theta})}\right)\cdot\underline{\Delta}\cdot\cos(\underline{\theta})\cdot\left[\frac{1}{2}\cdot\left(a_{\underline{\theta}} - \frac{o}{\cos(\underline{\theta})}\right)\cdot\cos(\underline{\theta})\right]\right] \ldots \\
+ \left[p_1\cdot\left|l_r - 2\cdot a_{\underline{\theta}}\right|\cdot\underline{\Delta}\cdot\cos(\underline{\theta})\cdot\left[\left(W - o - \frac{l_r}{2}\cdot\cos(\underline{\theta})\right) + \left(\frac{W}{2} - o - \frac{l_r}{2}\cdot\cos(\underline{\theta})\right)\right]\right] \ldots \\
+ -p_o\cdot\frac{o}{\cos(\underline{\theta})}\cdot\underline{\Delta}\cdot\cos(\underline{\theta})\cdot\left(\frac{o}{2}\right) \ldots \\
+ -\left[p_o\cdot\frac{o}{\cos(\underline{\theta})}\cdot\underline{\Delta}\cdot\sin(\underline{\theta})\cdot\left(\frac{o}{2\cdot\cos(\underline{\theta})}\cdot\sin(\underline{\theta})\right)\right] \ldots \\
+ -\left[p_2\cdot\left(a_{\underline{\theta}} - \frac{o}{\cos(\underline{\theta})}\right)\cdot\underline{\Delta}\cdot\sin(\underline{\theta})\cdot\left[\left[a_{\underline{\theta}} - \frac{1}{2}\cdot\left(a_{\underline{\theta}} - \frac{o}{\cos(\underline{\theta})}\right)\right]\cdot\sin(\underline{\theta})\right]\right] \ldots \\
+ -\left[p_1\cdot\left|l_r - 2\cdot a_{\underline{\theta}}\right|\cdot\underline{\Delta}\cdot\sin(\underline{\theta})\cdot\left(\frac{l_r}{2}\cdot\sin(\underline{\theta})\right)\right] \ldots \\
+ -\left[p_a\cdot a_{\underline{\theta}}\cdot\underline{\Delta}\cdot\sin(\underline{\theta})\cdot\left(l_r - \frac{a_{\underline{\theta}}}{2}\right)\cdot\sin(\underline{\theta})\right] \ldots \\
+ p_o\cdot\frac{o}{\cos(\underline{\theta})}\cdot\underline{\Delta}\cdot\sin(\underline{\theta})\cdot\left(\frac{o}{2\cdot\cos(\underline{\theta})}\cdot\sin(\underline{\theta})\right) \ldots \\
+ p_1\cdot\left|l_r - 2\cdot a_{\underline{\theta}}\right|\cdot\underline{\Delta}\cdot\sin(\underline{\theta})\cdot\left(\frac{l_r}{2}\cdot\sin(\underline{\theta})\right) \ldots \\
+ p_2\cdot a_{\underline{\theta}}\cdot\underline{\Delta}\cdot\sin(\underline{\theta})\cdot\left(l_r - \frac{a_{\underline{\theta}}}{2}\right)\cdot\sin(\underline{\theta}) \ldots \\
+ p_a\cdot\left(a_{\underline{\theta}} - \frac{o}{\cos(\underline{\theta})}\right)\cdot\underline{\Delta}\cdot\sin(\underline{\theta})\cdot\left[\left[a_{\underline{\theta}} - \frac{1}{2}\cdot\left(a_{\underline{\theta}} - \frac{o}{\cos(\underline{\theta})}\right)\right]\cdot\sin(\underline{\theta})\right] \ldots \\
+ \underline{\phi}\cdot DL_{roof}\cdot\underline{\Delta}\cdot W\cdot\left(\frac{W}{2} - o\right) + p_{int}\cdot\underline{\Delta}\cdot o\cdot\left[(o + -W + 2\cdot o) - \frac{o}{2}\right]
\end{array}\right]$$

$W = 30\,ft$

$l_r = 17.37\,ft$

$\underline{\Delta} = 2\,ft$

$$R_2 := \left[\left[\begin{array}{l} 2\cdot\left(p_o\cdot\frac{o}{\cos(\underline{\theta})}\cdot\cos(\underline{\theta})\cdot\underline{\Delta}\right) \ldots \\ +\left[p_2\cdot\left(a_{\underline{\theta}}-\frac{o}{\cos(\underline{\theta})}\right)\cdot\cos(\underline{\theta})\cdot\underline{\Delta}\right] \ldots \\ +\left(p_2\cdot a_{\underline{\theta}}\cdot\cos(\underline{\theta})\cdot\underline{\Delta}\right) \ldots \\ +2\cdot p_1\cdot\left(l_r-2\cdot a_{\underline{\theta}}\right)\cdot\cos(\underline{\theta})\cdot\underline{\Delta} \ldots \\ +\left(p_a\cdot a_{\underline{\theta}}\cdot\cos(\underline{\theta})\cdot\underline{\Delta}\right) \ldots \\ +p_a\cdot\left(a_{\underline{\theta}}-\frac{o}{\cos(\underline{\theta})}\right)\cdot\cos(\underline{\theta})\cdot\underline{\Delta}-2\cdot o\cdot p_{int}\cdot\underline{\Delta} \end{array}\right] + \underline{\phi}\cdot DL_{roof}\cdot\left(\underline{\Delta}\cdot W\right)\right] - R_1$$

$p_2 = -36.84\,psf$

$p_1 = -30.59\,psf$

$p_o = -56.19\,psf$

$p_a = -36.84\,psf$

$R_1 = -812.71\,lbf$

Last term subtracts out internal pressure on the overhang

$R_2 = -812.71\,lbf$

$Strap_1 := -R_2$

$Strap_1 = 812.71\,lbf$

1. Method 2 of ASCE-05 Components and Cladding For a End Truss

Effective wind area of a truss equals maximum of actual area and span times 1/3 span length

$$A_{eff.} := \left(\left(\begin{array}{c} W\cdot\underline{\Delta} \\ W\cdot\frac{W}{3} \end{array}\right)\right) \qquad A_{eff} = \begin{pmatrix} 60 \\ 300 \end{pmatrix} ft^2$$

$A_{eff} := \max(A_{eff})$

$A_{eff} = 300\,ft^2$

External Gust Factors

$GC_p(A_{eff}, 1) = \begin{pmatrix} -0.8 \\ 0.8 \end{pmatrix}$

$GC_p(A_{eff}, 2) = \begin{pmatrix} -1 \\ 0.8 \end{pmatrix}$

$GC_p(A_{eff}, 3) = \begin{pmatrix} -1 \\ 0.8 \end{pmatrix}$

$k := 1..3 \qquad p_k := \left(GC_p(A_{eff}, k)_0 + GC_{pi_0}\right)\cdot q_h$

$$p = \begin{pmatrix} 0 \\ -30.59 \\ -36.84 \\ -36.84 \end{pmatrix} psf$$

Design Pressures for Zones 1, 2, and 3

$p_{int.} := \left(GC_{pi_0}\right)\cdot q_h$

Overhang pressures

$p_{o.} := \left(GC_p(A_{eff}, 6)_0\right)\cdot q_h \qquad GC_p(A_{eff}, 6) = \begin{pmatrix} -1.8 \\ 0 \end{pmatrix} \qquad p_o = -56.19\,psf$

By Inspection Strap Load:

$F_{up} := -p_3\cdot\underline{\Delta}\cdot 2\cdot a + -p_2\cdot\underline{\Delta}\cdot(W - 2\cdot a) - \underline{\phi}\cdot DL_{roof}\underline{\Delta}\cdot W$

$F_{up} = 1850.18\,lbf$

$Strap_0 := \frac{F_{up}}{2}$

$Strap_0 = 925.09\,lbf$

ASCE-02 Method 2: Check MWFRS loading conditions:

Interpolate coefficients based on Figure 6-10: Walls and Gable&hip Roof.
Note that there are 8 loading conditions to design for with this method.

$$roofAng := \begin{pmatrix} 0 \\ 5 \\ 20 \\ 30 \\ 45 \\ 90 \end{pmatrix} \qquad GC_{pinput} := \begin{pmatrix} 0.4 & -0.69 & -0.37 & -0.29 & -0.45 & -0.45 & 0.61 & -1.07 & -0.53 & -0.43 \\ 0.4 & -0.69 & -0.37 & -0.29 & -0.45 & -0.45 & 0.61 & -1.07 & -0.53 & -0.43 \\ 0.53 & -0.69 & -0.48 & -0.43 & -0.45 & -0.45 & 0.8 & -1.07 & -0.69 & -0.64 \\ 0.56 & 0.21 & -0.43 & -0.37 & -0.45 & -0.45 & 0.69 & 0.27 & -0.53 & -0.48 \\ 0.56 & 0.21 & -0.43 & -0.37 & -0.45 & -0.45 & 0.69 & 0.27 & -0.53 & -0.48 \\ 0.56 & 0.56 & -0.37 & -0.37 & -0.45 & -0.45 & 0.69 & 0.669 & -0.48 & -0.48 \end{pmatrix}$$

$zonetrans := 0..9$ $zoneperp := 0..9$ Interpolated for roof slope $\underline{\theta} = 30.26deg$

Pressure coefficient by zone in Figure 6-10 in the transverse direction

$$GC_{1t} := linterp\left(roofAng, GC_{pinput}^{\langle 0 \rangle}, \frac{\underline{\theta}}{deg}\right) \qquad GC_{1Et} := linterp\left(roofAng, GC_{pinput}^{\langle 6 \rangle}, \frac{\underline{\theta}}{deg}\right)$$

$$GC_{2t} := linterp\left(roofAng, GC_{pinput}^{\langle 1 \rangle}, \frac{\underline{\theta}}{deg}\right) \qquad GC_{2Et} := linterp\left(roofAng, GC_{pinput}^{\langle 7 \rangle}, \frac{\underline{\theta}}{deg}\right)$$

$$GC_{3t} := linterp\left(roofAng, GC_{pinput}^{\langle 2 \rangle}, \frac{\underline{\theta}}{deg}\right) \qquad GC_{3Et} := linterp\left(roofAng, GC_{pinput}^{\langle 8 \rangle}, \frac{\underline{\theta}}{deg}\right)$$

$$GC_{4t} := linterp\left(roofAng, GC_{pinput}^{\langle 3 \rangle}, \frac{\underline{\theta}}{deg}\right) \qquad GC_{4Et} := linterp\left(roofAng, GC_{pinput}^{\langle 9 \rangle}, \frac{\underline{\theta}}{deg}\right)$$

$$GC_{5t} := linterp\left(roofAng, GC_{pinput}^{\langle 4 \rangle}, \frac{\underline{\theta}}{deg}\right)$$

$$GC_{6t} := linterp\left(roofAng, GC_{pinput}^{\langle 5 \rangle}, \frac{\underline{\theta}}{deg}\right)$$

$GC_{3Et} = -0.53$

$GC_{3t} = -0.43$

$GC_{ptrans} := \begin{pmatrix} GC_{1t} & GC_{2t} & GC_{3t} & GC_{4t} & GC_{5t} & GC_{6t} & GC_{1Et} & GC_{2Et} & GC_{3Et} & GC_{4Et} \end{pmatrix}$

$GC_{ptrans} =$

	0	1	2	3	4	5	6	7	8	9
0	0.56	0.21	-0.43	-0.37	-0.45	-0.45	0.69	0.27	-0.53	-0.48

Pressure coefficient by zone in Figure 6-10 in the perpendicular direction

Roof Slope equal 0, See Note 2 in Figure 6-4

$GC_{1p} := linterp(roofAng, GC_{pinput}\langle 0\rangle, 0)$ $GC_{1Ep} := linterp(roofAng, GC_{pinput}\langle 6\rangle, 0)$

$GC_{2p} := linterp(roofAng, GC_{pinput}\langle 1\rangle, 0)$ $GC_{2Ep} := linterp(roofAng, GC_{pinput}\langle 7\rangle, 0)$

$GC_{3p} := linterp(roofAng, GC_{pinput}\langle 2\rangle, 0)$ $GC_{3Ep} := linterp(roofAng, GC_{pinput}\langle 8\rangle, 0)$

$GC_{4p} := linterp(roofAng, GC_{pinput}\langle 3\rangle, 0)$ $GC_{4Ep} := linterp(roofAng, GC_{pinput}\langle 9\rangle, 0)$

$GC_{5p} := linterp(roofAng, GC_{pinput}\langle 4\rangle, 0)$

$GC_{6p} := linterp(roofAng, GC_{pinput}\langle 5\rangle, 0)$

$GC_{pperp} := |GC_{1p}\ GC_{2p}\ GC_{3p}\ GC_{4p}\ GC_{5p}\ GC_{6p}\ GC_{1Ep}\ GC_{2Ep}\ GC_{3Ep}\ GC_{4Ep}|$ $GC_{pi} = \begin{pmatrix} -0.18 \\ 0.18 \end{pmatrix}$

$GC_{pperp} =$

	0	1	2	3	4	5	6	7	8	9
0	0.4	-0.69	-0.37	-0.29	-0.45	-0.45	0.61	-1.07	-0.53	-0.43

$GC_{po} := 0.8$ Overhang pressure coefficient from 6.5.11.4.1

Check the Transverse direction

z = width of zone 2 on roof parallel to wind direction, varies for some cases $z := \begin{pmatrix} 0.5 \cdot W \\ 2.5 \cdot h \end{pmatrix}$ $z = \begin{pmatrix} 15 \\ 34.27 \end{pmatrix} ft$ $z := \min(z)$ $\underline{z} = 15 \underline{ft}$

$$z_{2E} := \begin{cases} z & \text{if } GC_{2Et} < 0 \\ \frac{W}{2} & \text{otherwise} \end{cases} \qquad z_2 := \begin{cases} z & \text{if } GC_{2t} < 0 \\ \frac{W}{2} & \text{otherwise} \end{cases}$$

Tributary Areas in plan that are affected by uplift pressures 1-4E from Figure 6-10

Roof areas

$Area_{3E} := 2a \cdot |W - z_{2E}|$ $Area_2 := (L - 2a) \cdot z_2$

$Area_{2E} := 2a \cdot z_{2E}$ $Area_3 := (L - 2a) \cdot |W - z_2|$

Overhang areas

$Area_o := L \cdot o$

Tributary Areas affected by lateral pressure

$Area_{1E} := h_{wall} \cdot 2a \cdot \frac{1}{2}$ $Area_{4E} := h_{wall} \cdot 2a \cdot \frac{1}{2}$ $Area_4 := \frac{L - 2a}{2}$ $Area_1 := \frac{L - 2a}{2}$

$$F_{transup} := q_h \cdot \left[\begin{array}{l} -GC_{3Et} \cdot Area_{3E} - GC_{2t} \cdot Area_2 - GC_{2Et} \cdot Area_{2E} - GC_{3t} \cdot Area_3 \ldots \\ + GC_{po} \cdot Area_o + GC_{pi_1} \cdot |L - 2 \cdot o_g| \cdot (W - 2 \cdot o) \end{array} \right] \ldots + -\underline{\phi} \cdot DL_{roof} \cdot L \cdot W$$

$F_{transup} = 5607.77 lbf$ positive indicates the force is upward

Sum moments about axis on which L is defined, assume straps are located only along lengths L

$$R_{2.} := \frac{q_h}{W - 2 \cdot o} \cdot \left[\begin{array}{l} -GC_{3Et} \cdot Area_{3E} \cdot \left(\frac{W - z_{2E}}{2} + z_{2E} - o \right) \ldots \\ + |-GC_{2t} \cdot Area_2| \cdot \left(\frac{z_{2E}}{2} - o \right) \ldots \\ + -GC_{2Et} \cdot Area_{2E} \cdot \frac{1}{2} \cdot \left(\frac{z_{2E}}{2} - o \right) \ldots \\ + -GC_{3t} \cdot Area_3 \cdot \left(\frac{W - z_2}{2} + z_2 \right) \ldots \\ + -GC_{po} \cdot \frac{o}{2} \cdot Area_o \ldots \\ + GC_{pi_1} \cdot L \cdot \frac{(W - 2 \cdot o)^2}{2} \end{array} \right] - \underline{\phi} \cdot DL_{roof} \cdot \frac{L \cdot W}{2}$$

$R_2 = 7506.37 lbf$

$$Strap_2 := \frac{\max\left[R_2, |F_{transup} - R_2|\right]}{\frac{L - 2 \cdot o}{\underline{\Delta}} + 1}$$

$Strap_2 = 242.14 lbf$

Check the Longitudinal direction

z = width of zone 2 on roof parallel to wind direction, varies for some cases

$z := \begin{pmatrix} 0.5 \cdot L \\ 2.5 \cdot h \end{pmatrix}$ $z = \begin{pmatrix} 30 \\ 34.27 \end{pmatrix} ft$ $z := \min(z)$

$z = 30 ft$

$$z_{2E.} := \begin{cases} z & \text{if } GC_{2Ep} < 0 \\ \frac{L}{2} & \text{otherwise} \end{cases} \qquad z_{2.} := \begin{cases} z & \text{if } GC_{2p} < 0 \\ \frac{L}{2} & \text{otherwise} \end{cases}$$

Tributary Areas in plan that are affected by uplift pressures 1-4E from Figure 6-10

Roof areas

$Area_{3E.} := 2a \cdot |L - z_{2E}|$ $Area_{2.} := (W - 2 \cdot a) \cdot z_2$

$Area_{2E.} := 2a \cdot z_{2E}$ $Area_{3.} := |L - z_2| \cdot (W - 2a)$

Overhang areas

$Area_{o.} := W \cdot o_g$

Total force acting upwards is:

$$F_{transup.} := q_h \cdot \begin{bmatrix} -GC_{3Ep} \cdot Area_{3E} - GC_{2p} \cdot Area_2 - GC_{2Ep} \cdot Area_{2E} \dots \\ + GC_{3p} \cdot Area_3 + GC_{po} \cdot Area_o \dots \\ + GC_{pi_1} \cdot |L - 2 \cdot o_g| \cdot (W - 2 \cdot o) \end{bmatrix} - \phi \cdot DL_{roof} \cdot (L \cdot W)$$

$F_{transup} = 15497.39 lbf$ This indicates the force is upward

Sum moments about axis on which L is defined

$$R_{2.} := \frac{q_h}{W - 2 \cdot o} \cdot \begin{bmatrix} -GC_{3Ep} \cdot Area_{3E} \cdot (a - o) \dots \\ + |-GC_{2p} \cdot Area_2| \cdot \left(2 \cdot a - o + \frac{W - 2 \cdot a}{2}\right) \dots \\ + -GC_{2Ep} \cdot Area_{2E} \cdot (a - o) \dots \\ + -GC_{3p} \cdot Area_3 \cdot \left(2 \cdot a - o + \frac{W - 2 \cdot a}{2}\right) \dots \\ + GC_{po} \cdot \left(\frac{W}{2} - o\right) \cdot Area_o \dots \\ + GC_{pi_1} \cdot L \cdot \frac{(W - 2 \cdot o)^2}{2} \end{bmatrix} - \phi \cdot DL_{roof} \cdot \frac{L \cdot W}{2}$$

$R_2 = \blacksquare lbf$

$R_2 = 14851.24 lbf$

$$Strap_3 := \frac{\max\left[R_2, |F_{transup} - R_2|\right]}{\frac{L - 2 \cdot o}{\Delta} + 1}$$

$Strap_3 = 479.07 lbf$

3: Calculate uplift on an interior truss using MWFRS (method 2) in ASCE-02

Transverse direction: Check for an interior truss in zone 2

z = width of zone 2 on roof parallel to wind direction, varies for some cases $z := \begin{pmatrix} 0.5 \cdot W \\ 2.5 \cdot h \end{pmatrix}$ $z = \begin{pmatrix} 15 \\ 34.27 \end{pmatrix} ft$ $z := \min(z)$

$z = 15 ft$

$$z_{2E.} := \begin{cases} z & \text{if } GC_{2Et} < 0 \\ \frac{W}{2} & \text{otherwise} \end{cases} \qquad z_{2.} := \begin{cases} z & \text{if } GC_{2t} < 0 \\ \frac{W}{2} & \text{otherwise} \end{cases}$$

Tributary Areas in plan that are affected by uplift pressures 1-4E from Figure 6-10

Roof areas

$Area_{2.} := \Delta \cdot z_2$

Overhang areas

$Area_{o.} := \Delta \cdot o$

$Area_{.3.} := |\Delta| \cdot |W - z_{.2}|$

$$F_{transup.} := q_h \cdot \left[-GC_{2t} \cdot Area_2 - GC_{3t} \cdot Area_3 + GC_{po} \cdot Area_o + GC_{pi_1} \cdot \Delta \cdot (W - 2 \cdot o) \right] - \phi \cdot DL_{roof} \cdot |\Delta \cdot W|$$

$F_{transup} = 183.18 lbf$

Sum moments about axis on which L is defined, assume straps are located only along lengths L

$$R_{2.} := \frac{q_h}{W - 2 \cdot o} \cdot \left[\begin{array}{l} \left| -GC_{2t} \cdot Area_2 \right| \cdot \left(\frac{z_2}{2} - o \right) \ldots \\ + -GC_{3t} \cdot Area_3 \cdot \left(\frac{W - z_2}{2} + z_2 \right) \ldots \\ + -GC_{po} \cdot \frac{o}{2} \cdot Area_o \ldots \\ + GC_{pi_1} \cdot \Delta \cdot \frac{(W - 2 \cdot o)^2}{2} \end{array} \right] - \phi \cdot DL_{roof} \cdot \frac{\Delta \cdot W}{2}$$

$R_2 = 241.43 lbf$

$Strap_4 := \max\left[R_2, \left| F_{transup} - R_2 \right| \right]$ $Strap_4 = 241.43 lbf$

Check the Longitudinal direction in zone 2/2E zone within z

z = width of zone 2 on roof parallel to wind direction, varies for some cases $z := \begin{pmatrix} 0.5 \cdot L \\ 2.5 \cdot h \end{pmatrix}$ $z = \begin{pmatrix} 30 \\ 34.27 \end{pmatrix} ft$ $z := \min(z)$ $z = 30 ft$

$$z_{2E.} := \begin{cases} z & \text{if } GC_{2Ep} < 0 \\ \frac{L}{2} & \text{otherwise} \end{cases}$$

$$z_{2.} := \begin{cases} z & \text{if } GC_{2p} < 0 \\ \frac{L}{2} & \text{otherwise} \end{cases}$$

Tributary Areas in plan that are affected by uplift pressures 1-4E from Figure 6-10

Roof areas

$Area_{2.} := (W - 2 \cdot a) \cdot \underline{\Delta}$

$Area_{2E.} := 2a \cdot \underline{\Delta}$

Overhang areas

$Area_{o.} := \underline{\Delta} \cdot o_g$

Total force acting upwards is:

$$F_{transup.} := q_h \cdot \left[\begin{array}{l} -GC_{2p} \cdot Area_2 - GC_{2Ep} \cdot Area_{2E} + GC_{po} \cdot Area_o \ldots \\ + GC_{pi_1} \cdot \underline{\Delta} \cdot (W - 2 \cdot o) \end{array} \right] - \underline{\phi} \cdot DL_{roof} \cdot \left(\underline{\Delta} \cdot W \right)$$

$F_{transup} = 1411.89 lbf$ This indicates the force is upward

Sum moments about axis on which L is defined

$$R_{2.} := \frac{q_h}{W - 2 \cdot o} \cdot \left[\begin{array}{l} \left(-GC_{2p} \cdot Area_2 \right) \cdot \left(2 \cdot a - o + \frac{W - 2 \cdot a}{2} \right) \ldots \\ + -GC_{2Ep} \cdot Area_{2E} \cdot (a - o) \ldots \\ + GC_{po} \cdot \left(\frac{W}{2} - o \right) \cdot Area_o \ldots \\ + GC_{pi_1} \cdot \underline{\Delta} \cdot \frac{(W - 2 \cdot o)^2}{2} \end{array} \right] - \underline{\phi} \cdot DL_{roof} \cdot \frac{\underline{\Delta} \cdot W}{2}$$

$R_2 = 649 lbf$

$Strap_5 := \max\left[R_2, \left(F_{transup} - R_2 \right) \right]$ $Strap_5 = 762.88 lbf$

Check the Longitudinal direction again but this time in zones 3/3E for a center truss

z = width of zone 3 on roof parallel to wind direction, varies for some cases

$z := \begin{pmatrix} 0.5 \cdot L \\ 2.5 \cdot h \end{pmatrix}$ $z = \begin{pmatrix} 30 \\ 34.27 \end{pmatrix} ft$ $z := \min(z)$

$z = 30 ft$

$z_{2E.} := \begin{cases} z & \text{if } GC_{2Ep} < 0 \\ \frac{L}{2} & \text{otherwise} \end{cases}$ $z_{2.} := \begin{cases} z & \text{if } GC_{2p} < 0 \\ \frac{L}{2} & \text{otherwise} \end{cases}$

Tributary Areas in plan that are affected by uplift pressures 1-4E from Figure 6-10

Roof areas

$Area_{3E.} := 2a \cdot |\Delta|$ $GC_{3Ep} = -0.53$

$Area_{3.} := |\Delta| \cdot (W - 2a)$ $GC_{3p} = -0.37$

Total force acting upwards is:

$$F_{transup.} := q_h \cdot \begin{bmatrix} -GC_{3Et} \cdot Area_{3E} - GC_{3t} \cdot Area_3 + GC_{po} \cdot Area_o \ ... \\ + GC_{pi_1} \cdot |\Delta| \cdot (W - 2 \cdot o) \end{bmatrix} - \phi \cdot DL_{roof} \cdot |\Delta \cdot W|$$

$F_{transup} = 730.11 lbf$ This indicates the force is upward

Sum moments about axis on which L is defined

$$R_{2.} := \frac{q_h}{W - 2 \cdot o} \cdot \begin{bmatrix} -GC_{3Et} \cdot Area_{3E} \cdot (a - o) \ ... \\ + -GC_{3t} \cdot Area_3 \cdot \left(2 \cdot a - o + \frac{W - 2 \cdot a}{2} \right) ... \\ + GC_{pi_1} \cdot \Delta \cdot \frac{(W - 2 \cdot o)^2}{2} \end{bmatrix} - \phi \cdot DL_{roof} \cdot \frac{\Delta \cdot W}{2}$$

$R_2 = 341.08 lbf$

$Strap_6 := \max\left[R_2, |F_{transup} - R_2| \right]$ $Strap_6 = 389.03 lbf$

Corner Straps - Method 1: Calculate uplift on Corner truss by end zone pressure from MWFRS loads

From inspection, zone 2/2E Controls.

Check the Longitudinal direction in zone 2/2E zone within z

z = width of zone 2 on roof parallel to wind direction, varies for some cases $z := \begin{pmatrix} 0.5 \cdot L \\ 2.5 \cdot h \end{pmatrix}$ $z = \begin{pmatrix} 30 \\ 34.27 \end{pmatrix} ft$ $z := \min(z)$ $z = 30ft$

$$z_{2E.} := \begin{cases} z & \text{if } GC_{2Ep} < 0 \\ \frac{L}{2} & \text{otherwise} \end{cases} \qquad z_{2.} := \begin{cases} z & \text{if } GC_{2p} < 0 \\ \frac{L}{2} & \text{otherwise} \end{cases}$$

Tributary Areas in plan that are affected by uplift pressures 1-4E from Figure 6-10

Roof areas

$Area_{2.} := (W - 2 \cdot a) \cdot \underline{\Delta}$

$Area_{2E.} := 2a \cdot \underline{\Delta}$

Overhang areas

$Area_{o.} := \underline{\Delta} \cdot o_g$

Total force acting upwards is:

$$F_{transup.} := q_h \cdot \begin{bmatrix} -GC_{2p} \cdot Area_2 - GC_{2Ep} \cdot Area_{2E} + GC_{po} \cdot Area_o \ ... \\ + GC_{pi_1} \cdot \underline{\Delta} \cdot (W - 2 \cdot o) \end{bmatrix} - \underline{\phi} \cdot DL_{roof} \cdot \left| \underline{\Delta} \cdot W \right|$$

$F_{transup} = 1411.89lbf$ This indicates the force is upward

Sum moments about axis on which L is defined

$$R_{2.} := \frac{q_h}{W - 2 \cdot o} \cdot \begin{bmatrix} \left| -GC_{2p} \cdot Area_2 \right| \cdot \left(2 \cdot a - o + \frac{W - 2 \cdot a}{2} \right) \ ... \\ + -GC_{2Ep} \cdot Area_{2E} \cdot (a - o) \ ... \\ + GC_{po} \cdot \left(\frac{W}{2} - o \right) \cdot Area_o \ ... \\ + GC_{pi_1} \cdot \underline{\Delta} \cdot \frac{(W - 2 \cdot o)^2}{2} \end{bmatrix} - \underline{\phi} \cdot DL_{roof} \cdot \frac{\underline{\Delta} \cdot W}{2}$$

$R_2 = 649lbf$

$Strap_7 := \max\left(\left| R_2, \left| F_{transup} - R_2 \right| \right| \right)$ $Strap_7 = 762.88lbf$

Summary of Strap Design

Strap Design of interior zone truss:

Components and Cladding: Interior Truss

corner $Strap_0 = 925.09\,lbf$

center $Strap_1 = 812.71\,lbf$

MWFRS Loads: summed over area

Positive values indicate uplift

corner $Strap_7 = 762.88\,lbf$

roof as a whole $Strap_2 = 242.14\,lbf$

roof as a whole $Strap_3 = 479.07\,lbf$

center $Strap_4 = 241.43\,lbf$

center $Strap_5 = 762.88\,lbf$

center $Strap_6 = 389.03\,lbf$

Use worst case of MWFRS as a representative load for the straps.

$$R_{design} := \max\left(Strap_2, Strap_3, Strap_4, Strap_5, Strap_6, Strap_7\right)$$

$$R_{design} = 762.88\,lbf$$

Shear on Roof-Wall Connectors via Component and Cladding

Lateral shear loads on connectors. Determine shear at each strap using the components and cladding method for an interior truss. I.E. (shear that corresponds to Strap1 force) Assume the worst case to induce shear. A portion of this is based on the wind normal and parallel to the ridge, and it is assumed that all straps act in unison to bear both loads

Shear Force Normal to the ridge for one center truss (not used)

$$Shear_{normc} := \underline{\Delta} \cdot \left[\left(h_{ridge} - 2 \cdot a \right) \cdot GC_p\left(\frac{W^2}{3}, 1\right) - 2a \cdot \tan\left(\underline{\theta}\right) \cdot GC_p\left(\frac{W^2}{3}, 2\right) \right] \cdot q_h$$

$$Shear_{normc} = \begin{pmatrix} 81.16 \\ -37.46 \end{pmatrix} lbf \qquad GC_p\left(\frac{W^2}{3}, 3\right) = \begin{pmatrix} -1 \\ 0.8 \end{pmatrix}$$

Shear Force Normal to the ridge
all straps resisting Sum portions for area1+2+3

$$\text{Shear}_{norm} := \left[\text{VPA}_{\perp} - \left[2\cdot a\cdot h_{ridge} + 2\cdot a\cdot\tan\left(\underline{\theta}\right)\cdot(L - 2\cdot a)\right]\right]\cdot\left(-GC_p\left(\frac{L^2}{3},1\right)_0 + GC_p\left(\frac{L^2}{3},1\right)_1\right)\cdot q_h \ldots$$

$$+\left[\left[2\cdot a\cdot h_{ridge} + 2\cdot a\cdot\tan\left(\underline{\theta}\right)\cdot(L - 2\cdot a)\right] - 4\cdot\left|a^2\cdot\tan\left(\underline{\theta}\right)\right|\right]\cdot\left(-GC_p\left(\frac{L^2}{3},2\right)_0 + GC_p\left(\frac{L^2}{3},2\right)_1\right)\cdot q_h \ldots$$

$$+4\cdot\left|a^2\cdot\tan\left(\underline{\theta}\right)\right|\cdot\left(-GC_p\left(\frac{L^2}{3},3\right)_0 + GC_p\left(\frac{L^2}{3},3\right)_1\right)\cdot q_h$$

$$\text{Shear}_{norm} = 27730.26\,\text{lbf}$$

Shear Force Parallel to the ridge
all straps resisting. Sum portions for area1+2+3

$$\text{Shear}_{par} := \left(\text{VPA}_{\parallel} - a^2\cdot\tan\left(\underline{\theta}\right)\right)\cdot\left(-GC_p\left(\frac{W^2}{3},4\right)_0 + GC_p\left(\frac{W^2}{3},4\right)_1\right)\cdot q_h \ldots$$

$$+\left|a^2\cdot\tan\left(\underline{\theta}\right)\right|\cdot\left(-GC_p\left(\frac{W^2}{3},5\right)_0 + GC_p\left(\frac{W^2}{3},5\right)_1\right)\cdot q_h$$

$$\text{Shear}_{par} = 6.42\,\text{lbf}$$

In this instance, straps as well as nail connections attached to stud frame walls will resist the shear. Assume that bottom chord of gable end truss is attached to blocking with 16d nails at 16in o.c.. This block is in turned attached to double top plate. Ignore this connection and assume all forces are taken up by the straps.

$$\text{Strap}_{shear} := \frac{\max\left(\text{Shear}_{norm}, \text{Shear}_{par}\right)}{\text{Straps}_{total}}$$

$$\text{Strap}_{shear} = 478.11\,\text{lbf}$$

WALL DESIGN for Wood Frame Walls

Nominal Wall Design Parameters

Exterior Surface: 3/8" OSB 24/0 span rating
Interior Surface: 1/2" Gypsum

min thickness Table 2308.9.3(2), 2308.9.3(3)

$t_{OSB} := \frac{3}{8} \cdot in$

spacing of studs option variable

nail Size: 6d common Table FBC 2004 Res R602.3(1)

$\Delta_{stud} := \begin{pmatrix} 12 \\ 16 \end{pmatrix} in$ Spacing of studs in wall, 2 options considered

$sp := 0..1$

Lumber Design Values from Table 4B, NDS-S 1997

Bending stress, allowable $F_{b.} := 1500 psi$
Tension Parallel to grain, allowable $F_{v.} := 175 psi$
Shear parallel to grain, allowable $F_{t.} := 825 psi$
Compression Perpendicular to grain $Fcp := 565 psi$
Compression Parallel to grain $F_{c.} := 1650 psi$
Modulus of Elasticity $E := 1600000 psi$

Species and Grade:
Southern Pine, No 2.
to be used for stud parameters

Properties of OSB from NDS

$EI_{OSB} := 60000 lbf \cdot \frac{in^2}{ft}$ Stiffness of OSB panel at 24/0 per foot of width

NDS 2005 manual table M9.2-1

$FbS_{OSB} := 300 lbf \cdot \frac{in}{ft}$ Bending Strength of OSB panel per foot of strength

Find allowable bending strength of OSB panel

$S := \frac{\frac{1}{12} \cdot 12 \cdot in \cdot t_{OSB}^3}{\frac{t_{OSB}}{2}}$ $S = 0.28 in^3$ $E_{OSB} := \frac{EI_{OSB} \cdot ft}{\frac{1}{12} \cdot 12 \cdot in \cdot t_{OSB}^3}$

$F_{bOSB} := \frac{FbS_{OSB} \cdot 1 ft}{S}$ $F_{bOSB} = 1066.67 psi$ $E_{OSB} = 1.14 \times 10^6 psi$

$E = 1.6 \times 10^6 psi$

$n := \frac{E_{OSB}}{E}$ OSB is much stiffer than the studs on which it is attached. account for this in the following calcs

Shear capacity

$Fs_ibQ_{OSB} := 130\frac{lbf}{ft}$ Table M9.2-3 wood structural panel rolling shear capacity

Resistance of Wall (Wood): Consider three stud sizes - 2x4, 2x6 and 2x8's

$Stud_w := \begin{pmatrix} 1.5\cdot in \\ 1.5\cdot in \\ 1.5\cdot in \end{pmatrix}$ $Stud_{d.} := \begin{pmatrix} 3.5\cdot in \\ 5.5\cdot in \\ 7.25\cdot in \end{pmatrix}$ 2x4 wall, Dressed dim, Table 1A from NDS 2005-Sup
2x6 wall
2x8 wall

$isize := 0..2$

$Stud_{area.} := \overrightarrow{Stud_w \cdot Stud_d}$ $Stud_{area} = \begin{pmatrix} 5.25 \\ 8.25 \\ 10.87 \end{pmatrix} in^2$

Section modulus of lumber: NDS 2005 sup. Table 1B Moment of Inertia

$S_{xx_stud} := \begin{pmatrix} 3.063 \\ 7.563 \\ 13.14 \end{pmatrix} \cdot in^3$ $S_{yy_stud} := \begin{pmatrix} 1.313 \\ 2.063 \\ 2.719 \end{pmatrix} \cdot in^3$ $I_{xx_stud.} := \begin{pmatrix} 5.359 \\ 20.80 \\ 47.63 \end{pmatrix} \cdot in^4$ $I_{yy_stud} := \begin{pmatrix} 0.984 \\ 1.547 \\ 2.039 \end{pmatrix} \cdot in^4$

Consider composite section of portion of sheathing together with stud: Calculate section modulus for bending. This assumes that the strength values for OSB/plywood are similar to the strength values of the wood - otherwise an effective section modulus for dissimilar materials must be performed.

Sheathing $\phi_{width} := 1.0$ Set an effective width which will contribute to bending capacity of net section. 25% of stud spacing is about 2 times width of stud as initial guess.

Effective width of panel is clear span plus support plus 1/4" use oc spacing. conservative. NDS 2005 9.4.1

$Sheath_{area.} := |\Delta_{stud} \cdot \phi_{width}| \cdot t_{OSB} \cdot n$ $Sheath_{area} = \begin{pmatrix} 3.2 \\ 4.27 \end{pmatrix} in^2$

$I_{xx_sheath._{sp}} := \frac{|\Delta_{stud_{sp}} \cdot \phi_{width}| \cdot t_{OSB}^3 \cdot n}{12}$ $I_{xx_sheath} = \begin{pmatrix} 0.04 \\ 0.05 \end{pmatrix} in^4$ about it's centroid

distance of centroid of composite section

$$y_{c_{isize,sp}} := \frac{Stud_{area_{isize}} \cdot \frac{Stud_{d_{isize}}}{2} + Sheath_{area_{sp}} \cdot \left(Stud_{d_{isize}} + \frac{t_{OSB}}{2}\right)}{Stud_{area_{isize}} + Sheath_{area_{sp}}}$$

$y_c = \begin{pmatrix} 2.48 & 2.62 \\ 3.57 & 3.75 \\ 4.49 & 4.7 \end{pmatrix} in$ compared to: $\frac{Stud_d}{2} = \begin{pmatrix} 1.75 \\ 2.75 \\ 3.62 \end{pmatrix} in$

Net Moment of Inertia about centroid axis:

$$I_{xx_{isize,sp}} := I_{xx_stud_{isize}} + Stud_{area_{isize}} \cdot \left(y_{c_{isize,sp}} - \frac{Stud_{d_{isize}}}{2} \right)^2 \ldots$$

$$+ I_{xx_sheath_{sp}} + Sheath_{area_{sp}} \cdot \left(Stud_{d_{isize}} + \frac{t_{OSB}}{2} - y_{c_{isize,sp}} \right)^2$$

$$I_{xx} = \begin{pmatrix} 12.86 & 14.24 \\ 40.73 & 45.12 \\ 83.61 & 92.22 \end{pmatrix} in^4$$ compared to stud alone: $$I_{xx_stud} = \begin{pmatrix} 5.36 \\ 20.8 \\ 47.63 \end{pmatrix} in^4$$

Net Section Modulus:

$$S_{xx} := \frac{\overrightarrow{I_{xx}}}{y_c}$$

$$S_{xx} = \begin{pmatrix} 5.18 & 5.44 \\ 11.41 & 12.03 \\ 18.61 & 19.62 \end{pmatrix} in^3$$ compared to stud alone: $$S_{xx_stud} = \begin{pmatrix} 3.06 \\ 7.56 \\ 13.14 \end{pmatrix} in^3$$

1. Wall Sheathing Attachment - Suction Loads for Zone 5 C&C loads

Examine C&C pressures vs MWFRS pressures

MWFRS

Zones 1, 1E, 4E, 4, 5, 6 are examined $$GC_{pi} = \begin{pmatrix} -0.18 \\ 0.18 \end{pmatrix}$$

Perpendicular direction

$GC_{1p} = 0.4$ $GC_{1Ep} = 0.61$ $GC_{4Ep} = -0.43$ $GC_{4p} = -0.29$ $GC_{5p} = -0.45$ $GC_{6p} = -0.45$

Transverse direction

$GC_{1t} = 0.56$ $GC_{1Et} = 0.69$ $GC_{4Et} = -0.48$ $GC_{4t} = -0.37$ $GC_{5t} = -0.45$ $GC_{6t} = -0.45$

Components and clad zones 4&5

$$p_{wall} := q_h \cdot \left| GC_p\left(A_{eff}, 4\right) + GC_{pi} \right|$$ $$GC_p(Area, 4) + GC_{pi} = \begin{pmatrix} -1.19 \\ 1.09 \end{pmatrix}$$

$$GC_p(Area, 5) + GC_{pi} = \begin{pmatrix} -1.4 \\ 1.09 \end{pmatrix}$$

By inspection, component and cladding loads control

assume 6" spacing of fasteners as per FBC 2004/7 using 6d nails

Loads:

$Area := 32 \cdot ft^2$ Cladding loads $A_{eff.} := 1 \cdot ft^2$

$p_{wall.} := q_h \cdot \left(GC_p \left(A_{eff}, 5 \right) + GC_{pi} \right)$ Effective Area for one fastener

$p_{wall_0} = -49.32 psf$

Resistance of nails in panel:

$q_{.r.} := 41 \cdot \frac{lbf}{in}$ 6d common nail in Southern Pine (SG = 0.55)

$l_{nail.} := 2in$ length of nail, 6d

$l_{p.} := l_{nail} - t_{OSB}$ $l_p = 1.63in$ penetration length

$C_{D.} := 1.6$ Duration factor for short term loads - wind = 10 minutes

$C_{m.} := 1.0$ Condition Factor = assume that wood moisture content at time of construction is same as long term value

$R_{nail.} := q_r \cdot l_p \cdot C_D \cdot C_m$ $R_{nail} = 106.6 lbf$ per nail

2. Wall Bending & Axial Loads (component and cladding method from ASCE-02)

Check the adequacy of wall framing in zone 5. Treat them a stud and T-beam composite member

Wind Load:

$$A_{eff._{sp}} := \left(\begin{pmatrix} h_{wall} \cdot \Delta_{stud_{sp}} \\ \frac{h_{wall}^2}{3} \end{pmatrix} \right)$$

For Stud Spacing: $\Delta_{stud_0} = 12in$ $A_{eff_0} = \begin{pmatrix} 9 \\ 27 \end{pmatrix} ft^2$ $A_{eff_0} := \max\left(A_{eff_0} \right)$ $A_{eff_0} = 27 ft^2$

For Stud Spacing: $\Delta_{stud_1} = 16in$ $A_{eff_1} = \begin{pmatrix} 12 \\ 27 \end{pmatrix} ft^2$ $A_{eff_1} := \max\left(A_{eff_1} \right)$ $A_{eff_1} = 27 ft^2$

The one third span run tends to govern for all stud spacing, therefore limit effective area to just one area.

$A_{eff} := \max\left(A_{eff} \right)$ $A_{eff} = 27 ft^2$

By inspection zone 5 controls

$p_{wall.} := q_h \cdot \left(GC_p \left(A_{eff}, 5 \right) + GC_{pi} \right)$ $p_{wall} = \begin{pmatrix} -44.57 \\ 34.46 \end{pmatrix} psf$

Check Individual panel of OSB in zone 5

Flexure

$M_{Wallsheath} := \Delta^2 \cdot \frac{p_{wall_0} \cdot 1ft}{10}$ $M_{sheath} = -17.23 lbf \cdot ft$

$\sigma_{wallBending} := \frac{M_{Wallsheath}}{S}$ $\sigma_{wallBending} = -760.62 psi$ $F_{bOSB} = 1066.67 psi$

$PASS := 1$ $FAIL := 0$

$Status_{panelFlex} := \begin{cases} PASS & \text{if } |\sigma_{wallBending}| \le F_{bOSB} \\ FAIL & \text{otherwise} \end{cases}$ $Status_{panelFlex} = 1$

Shear

$Fs_ibQ_{OSB} = 130 \frac{1}{ft} lbf$

$Panel_{shearosb} := (\Delta - 1.5in) \cdot p_{wall_0} \cdot 1ft \cdot 0.6$ $Panel_{shearosb} = -50.14 lbf$ per foot of panel

$Status_{.sheathshear} := Fs_ibQ_{OSB} \cdot 1ft > |Panel_{shearosb} \cdot C_s \cdot C_t \cdot C_m|$ PASS = 1, FAIL = 0 $Status_{sheathshear} = 1$

Design the stud wall as a T section in zone 5

$DL_{roof} = 10 psf$

$L_{attic} = 30 psf$ FBC Table 1607.1

$L_{rooflive} := 18 \cdot psf$ FBC 1607.11.2.1

$DL_{.wall} := \begin{pmatrix} 35 \\ 192.5 \end{pmatrix} \cdot \frac{lbf}{ft}$ Wood Frame wall weight per unit length of wall
Masonry Wall Weight.

$DL_{Ceiling} := 10 psf$ Assumed weight of the ceiling

1. Look at the case where maximum overturning forces exist, examine wall for largest load in this case for a wood wall

Load acting per unit length of wall. Assume half of the ceiling/roof loads are taken by interior walls

Axial loads due to dead and live loads

$L_{Dead} := -DL_{wall} + \frac{-0.5 \cdot (DL_{Ceiling} + DL_{roof}) \cdot W \cdot L}{2 \cdot (W - 2 \cdot o + L)}$ $L_{Dead_0} = -135 \frac{lbf}{ft}$

$L_{Live} := \frac{-0.5 \cdot (L_{attic} + L_{rooflive}) \cdot W \cdot L}{2 \cdot (W - 2 \cdot o + L)}$ $L_{Live} = -240 \frac{lbf}{ft}$

Negative indicates a compressive force

Axial loads due to wind (component and cladding method) due to overturning loads

determine loads per unit length of wall. In this case examine wall parallel to the ridge

$A_{wallperp} := L \cdot h_{wall}$ $A_{wallperp} = 540\,ft^2$ Wall area perpendicular to the ridge

$A_{wallpar} := W \cdot h_{wall}$ $A_{wallpar} = 270\,ft^2$ Wall area parallel to the ridge

$p_{wall4} := q_h \cdot \left(GC_p\left(A_{eff}, 4 \right) + GC_{pi} \right)$ $p_{wall4} = \begin{pmatrix} -37.58 \\ 34.46 \end{pmatrix} psf$

$p_{wall5} := q_h \cdot \left(GC_p\left(A_{eff}, 5 \right) + GC_{pi} \right)$ $p_{wall5} = \begin{pmatrix} -44.57 \\ 34.46 \end{pmatrix} psf$ $\left| p_{wall4_1} \right| + \left| p_{wall4_0} \right| = 72.04 psf$

Loads acting on the roof due to wind component and cladding

$Shear_{norm} = 27730.26 lbf$ $Shear_{par} = 6.42 lbf$

Overturning wind force, sum about axis parallel to roof ridge at the bottom plate of the wall (worst axis):

$$M_{perp} := Shear_{norm} \cdot h + \left(A_{wallperp} - 2 \cdot a \cdot h_{wall} \right) \cdot \left(\left| p_{wall4_1} \right| + \left| p_{wall4_0} \right| \right) \cdot \frac{h_{wall}}{2} \ldots + \left(2 \cdot a \cdot h_{wall} \right) \cdot \left(\left| p_{wall5_1} \right| + \left| p_{wall5_0} \right| \right) \cdot \frac{h_{wall}}{2}$$

$F_{wAxial} := \frac{M_{perp}}{W - 2 \cdot o}$ $F_{wAxial} = 18562.93 lbf$

Load per unit length of wall:

$L_{wind} := \begin{pmatrix} \frac{F_{wAxial}}{L - 2 \cdot o} \\ -\frac{F_{wAxial}}{L - 2 \cdot o} \end{pmatrix}$ $L_{wind} = \begin{pmatrix} 309.38 \\ -309.38 \end{pmatrix} \frac{1}{ft} lbf$ This force can be either tensile (+) or compressive in nature(-)

Moment per unit length of wall. Only moment due to wind is induced in the wall. Assume a section in zone 5

$M_{wall} := \frac{p_{wall} \cdot h_{wall}^2 \cdot \Delta_{stud_1}}{8}$ $M_{wall} = \begin{pmatrix} -601.66 \\ 465.19 \end{pmatrix} lbf \cdot ft$

Load combinations to consider according to FBC 1605.3

For axial Loads

$Axial_{DLW} := L_{wind} + L_{Dead_0} + L_{Live}$ $Axial_{DLW} = \begin{pmatrix} -65.62 \\ -684.38 \end{pmatrix} \frac{1}{ft} lbf$

$Axial_{DW} := L_{wind} + 0.6 L_{Dead_0}$ $Axial_{DW} = \begin{pmatrix} 228.38 \\ -390.38 \end{pmatrix} \frac{1}{ft} lbf$ Other combinations do not control by inspection

Dead + Live + Wind

Dead·0.6 + Wind

For Moment

$M_{wall} = \begin{pmatrix} -601.66 \\ 465.19 \end{pmatrix}$ ft lbf Only wind loads act on the wall

$M_{wallMax} := \max\left(\left|M_{wall_0}\right|, \left|M_{wall_1}\right|\right)$ $M_{wallMax} = 601.66\,\text{ft lbf}$

Shear - Assume exterior walls absorb all wind forces

$Lat_{wind} := Shear_{norm} + \left(A_{wallperp} - 2\cdot a\cdot h_{wall}\right)\cdot\left(\left|p_{wall4_1}\right| + \left|p_{wall4_0}\right|\right) + \left(2\cdot a\cdot h_{wall}\right)\cdot\left(\left|p_{wall5_1}\right| + \left|p_{wall5_0}\right|\right)$

$S_{wind} := \frac{Lat_{wind}}{2\cdot\left(W - 2\cdot o + L - 2\cdot o_g\right)}$ $S_{wind} = 372.27\,\frac{1}{\text{ft}}\,\text{lbf}$

Lumber Property Adjustments

$C_{Dwind} := 1.6$ $C_L := 1.0$ Continuous Lateral Bracing (from sheathing)

$C_{Dgravity} := 0.9$

$C_r := \begin{pmatrix} 1.5 \\ 1.4 \\ 1.3 \end{pmatrix}$ Repetitive Loading Factor, from Table 2306.2.1 FBC pg 23.20 assuming 3/8 sheathing with gypsum board, and 8d nails at 6"/12" spacing

$C_F := \begin{pmatrix} 1.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 1.0 \end{pmatrix}$ for compression, for tension, for bending Size Factor, Not applicable to Southern Pine

2 x4, x6, x8

Calculate Adjusted Bending Capacity

$F_{b_a_{isize}} := F_b\cdot C_{Dwind}\cdot C_L\cdot\left(C_F^{\langle isize\rangle}\right)_2\cdot C_{r_{isize}}$ $F_{b_a} = \begin{pmatrix} 3600 \\ 3360 \\ 3120 \end{pmatrix}$ psi

Calculate adjusted compressive Capacity

$F_{c_star_{isize}} := F_c\cdot C_{Dgravity}\cdot\left(C_F^{\langle isize\rangle}\right)_0$ $F_{c_star} = \begin{pmatrix} 1485 \\ 1485 \\ 1485 \end{pmatrix}$ psi Conservative gravity Cd factor used

Euler Buckling Load

$K_{cE} := 0.82$ visually graded lumber $K_l := 1.0$ Effective length factor (Assume pin-pin column)

$c := 0.8$ sawn lumber

NDS 2005 page 156 in appendix G

$$F_{cE} := \frac{K_{cE} \cdot E}{\left(\frac{K_l \cdot h_{wall}}{Stud_d}\right)^2} \qquad F_{cE} = \begin{pmatrix} 1381.28 \\ 3410.91 \\ 5926.8 \end{pmatrix} psi$$ Euler buckling stress

$$C_{p_col} := \left[\frac{1 + \frac{F_{cE}}{F_{c_star}}}{2 \cdot c} - \sqrt{\left(\frac{1 + \frac{F_{cE}}{F_{c_star}}}{2 \cdot c} \right)^2 - \frac{\frac{F_{cE}}{F_{c_star}}}{c}} \right] \qquad C_{p_col} = \begin{pmatrix} 0.67 \\ 0.89 \\ 0.94 \end{pmatrix}$$ Column stability factor

$$F_{c_a_{isize}} := F_c \cdot C_{Dwind} \cdot \left(C_F^{\langle isize \rangle} \right)_0 \cdot C_{p_col_{isize}} \qquad F_{c_a} = \begin{pmatrix} 1756.76 \\ 2344.44 \\ 2486.41 \end{pmatrix} psi$$

Combined Bending and Axial Compression Capacity for Wind, Dead and Live load using combined stress interaction equation NDS 3.9.3 (also see p3.27 of Wood Engineering and Construction Handbook)

For Stud Spacing of: $sp := 1$ $\Delta_{stud_{sp}} = 16in$

Bending stress for: $f_{b_{isize}} := \frac{M_{wallMax}}{S_{xx_{isize,sp}}}$

$f_{b_{isize}} =$

1327.26
600.32
367.91

psi

compressive stress $f_c := \frac{Axial_{DLW_1} \cdot \Delta_{stud_{sp}}}{Stud_{area}}$ $f_c = \begin{pmatrix} -173.81 \\ -110.61 \\ -83.91 \end{pmatrix} psi$

Allowable values: $F_{c_a} = \begin{pmatrix} 1756.76 \\ 2344.44 \\ 2486.41 \end{pmatrix} psi$ $F_{b_a} = \begin{pmatrix} 3600 \\ 3360 \\ 3120 \end{pmatrix} psi$

Interaction Equation:

$$axial_{isize} := \left(\frac{f_{c_{isize}}}{F_{c_a_{isize}}} \right)^2 \qquad bend_{isize} := \frac{f_{b_{isize}}}{F_{b_a_{isize}} \cdot \left(1 - \frac{f_{c_{isize}}}{F_{cE_{isize}}} \right)}$$

$$axial = \begin{pmatrix} 0.01 \\ 0.002 \\ 0.001 \end{pmatrix} \qquad bend = \begin{pmatrix} 0.33 \\ 0.17 \\ 0.12 \end{pmatrix} \qquad PASS := 1$$

$$CSIequation_{isize} := axial_{isize} + bend_{isize} \qquad CSIequation = \begin{pmatrix} 0.34 \\ 0.18 \\ 0.12 \end{pmatrix}$$

$$Wood_Bending2x4 := \begin{cases} PASS & \text{if } |CSIequation_0| \le 1.0 \\ FAIL & \text{otherwise} \end{cases} \qquad Wood_Bending2x4 = 1$$

$$Wood_Bending2x6 := \begin{cases} PASS & \text{if } |CSIequation_1| \le 1.0 \\ FAIL & \text{otherwise} \end{cases} \qquad Wood_Bending2x6 = 1$$

$$Wood_Bending2x8 := \begin{cases} PASS & \text{if } |CSIequation_2| \le 1.0 \\ FAIL & \text{otherwise} \end{cases} \qquad Wood_Bending2x8 = 1$$

2. Check Maximum Axial Load when only Dead and Wind Loads Act

Examine maximum tensile case if axial load is compressive, skip this section

$$L_{Dead_0} = -135 \frac{1}{ft} lbf$$

$$L_{wind} := R_{design} \cdot \frac{\Delta_{stud_1}}{\Delta} \qquad L_{wind} = 508.59 lbf$$ Strap force transmitted to wall studs below

$$Axial_{DW} := \frac{L_{wind}}{\Delta_{stud_1}} + 0.6 L_{Dead_0} \qquad Axial_{DW} = 300.44 \frac{1}{ft} lbf$$

Other combinations do not control by inspection

$$M_{wallMax} = 601.66 ft\,lbf$$

Moment in the stud due to wind

$$C_{D.wind} := 1.6$$

$$C_{D.gravity} := 0.9$$

$$C_{.L} := 1.0$$ Continuous Lateral Bracing (from sheathing)

$$C_r := \begin{pmatrix} 1.5 \\ 1.4 \\ 1.3 \end{pmatrix}$$ Repetitive Loading Factor, from Table 2306.2.1 FBC pg 23.20 assuming 3/8 sheathing with gypsum board, and 8d nails at 6"/12" spacing

$$C_F := \begin{pmatrix} 1.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 1.0 \end{pmatrix}$$ for compression, for tension, for bending — Size Factor, Not applicable to Southern Pine

2 x4, x6, x8

Calculate Adjusted Bending Capacity

$$F_{b_a_{isize}} := F_b \cdot C_{Dwind} \cdot C_L \cdot \left| C_F^{\langle isize \rangle} \right|_2 \cdot C_{r_{isize}} \qquad F_{b_a} = \begin{pmatrix} 3600 \\ 3360 \\ 3120 \end{pmatrix} psi$$

$$f_b := \frac{Axial_{DLW_1} \cdot \Delta_{stud_{sp}}}{Stud_{area}}$$

Calculate adjusted tensile Capacity

$$F_{t_star_{isize}} := F_t \cdot C_{Dgravity} \cdot \left| C_F^{\langle isize \rangle} \right|_0 \qquad F_{c_star} = \begin{pmatrix} 1485 \\ 1485 \\ 1485 \end{pmatrix} psi$$

conservative for Cd factor

Bending stress for:

$$f_{b_{isize}} := \frac{M_{wallMax}}{S_{xx_{isize,sp}}}$$

$f_{b_{isize}} =$

1327.26	psi
600.32	
367.91	

tensile stress

$$f_t := \frac{Axial_{DW} \cdot \Delta_{stud_{sp}}}{Stud_{area}} \qquad f_t = \begin{pmatrix} 40.26 \\ 25.62 \\ 19.44 \end{pmatrix} psi$$

$$axial_{isize} := \left(\frac{f_{t_{isize}}}{F_{t_star_{isize}}} \right) \qquad axial = \begin{pmatrix} 0.103 \\ 0.065 \\ 0.05 \end{pmatrix} \qquad bend_{isize} := \frac{f_{b_{isize}}}{F_{b_a_{isize}}} \qquad bend = \begin{pmatrix} 0.37 \\ 0.18 \\ 0.12 \end{pmatrix}$$

$$CSIequation_{isize} := axial_{isize} + bend_{isize} \qquad CSIequation = \begin{pmatrix} 0.47 \\ 0.24 \\ 0.17 \end{pmatrix}$$

$$Status_{axial_2x4} := \begin{cases} 1 & \text{if } |CSIequation_0| \le 1.0 \\ 0 & \text{otherwise} \end{cases} \qquad Status_{axial_2x4} = 1$$

$$Status_{axial_2x6} := \begin{cases} 1 & \text{if } |CSIequation_1| \le 1.0 \\ 0 & \text{otherwise} \end{cases} \qquad Status_{axial_2x6} = 1$$

$$Status_{axial_2x8} := \begin{cases} 1 & \text{if } |CSIequation_2| \le 1.0 \\ 0 & \text{otherwise} \end{cases} \qquad Status_{axial_2x8} = 1$$

Lateral Shear Design of Wood Walls

Assume that the walls act in unison to resist shear as a whole, use MWFRS to determine loads using ASCE-02 Figure 6-6

1. Wind Loads

$h_{wall} = 9\ ft$

$C_{p_wall_windward} := 0.8$

$\frac{L}{W} = 2 \qquad \frac{h}{L} = 0.23 \qquad \frac{h}{W} = 0.46$

$$L_B_ratio := \begin{pmatrix} 0 \\ 1 \\ 2 \\ 4 \\ 1000 \end{pmatrix} \qquad C_{p_w_lee} := \begin{pmatrix} -0.5 \\ -0.5 \\ -0.3 \\ -0.2 \\ -0.2 \end{pmatrix}$$

$$C_{p_wall_leeward} := linterp\left(L_B_ratio, C_{p_w_lee}, \min\left(\frac{L}{W}, \frac{W}{L}\right)\right) \qquad C_{p_wall_leeward} = -0.5$$

$C_{p_wall_side} := -0.7$

$$C_{p_roof_leeward_\Gamma} := \begin{cases} linterp\left[\begin{pmatrix} 10deg \\ 15deg \\ 20deg \\ 90deg \end{pmatrix}, \begin{pmatrix} -0.3 \\ -0.5 \\ -0.6 \\ -0.6 \end{pmatrix}, \underline{\theta}\right] & \text{if } \frac{h}{W} \le 0.25 \\ linterp\left[\begin{pmatrix} 0.25 \\ 0.5 \end{pmatrix}, \begin{bmatrix} linterp\left[\begin{pmatrix} 10deg \\ 15deg \\ 20deg \\ 90deg \end{pmatrix}, \begin{pmatrix} -0.3 \\ -0.5 \\ -0.6 \\ -0.6 \end{pmatrix}, \underline{\theta}\right] \\ linterp\left[\begin{pmatrix} 10deg \\ 15deg \\ 20deg \\ 90deg \end{pmatrix}, \begin{pmatrix} -0.5 \\ -0.5 \\ -0.6 \\ -0.6 \end{pmatrix}, \underline{\theta}\right] \end{bmatrix}, \frac{h}{W}\right] & \text{if } 0.25 < \frac{h}{W} \le 0.5 \\ linterp\left[\begin{pmatrix} 0.5 \\ 1.0 \end{pmatrix}, \begin{bmatrix} linterp\left[\begin{pmatrix} 10deg \\ 15deg \\ 20deg \\ 90deg \end{pmatrix}, \begin{pmatrix} -0.5 \\ -0.5 \\ -0.6 \\ -0.6 \end{pmatrix}, \underline{\theta}\right] \\ linterp\left[\begin{pmatrix} 10deg \\ 15deg \\ 20deg \\ 90deg \end{pmatrix}, \begin{pmatrix} -0.7 \\ -0.6 \\ -0.5 \\ -0.5 \end{pmatrix}, \underline{\theta}\right] \end{bmatrix}, \underline{\theta}\right] & \text{if } 0.5 < \frac{h}{W} < 1.0 \\ linterp\left[\begin{pmatrix} 10deg \\ 15deg \\ 20deg \\ 90deg \end{pmatrix}, \begin{pmatrix} -0.7 \\ -0.6 \\ -0.5 \\ 0.5 \end{pmatrix}, \underline{\theta}\right] & \text{otherwise} \end{cases}$$

$C_{p\ roof\ leeward\ \Gamma} = -0.6$

$$C_{p_roof_Windward1_\Gamma} := \begin{cases} \operatorname{linterp}\left[\begin{pmatrix}10\,deg\\15\,deg\\20\,deg\\25\,deg\\30\,deg\\35\,deg\\45\,deg\\60\,deg\\90\,deg\end{pmatrix}, \begin{pmatrix}-0.7\\-0.5\\-0.3\\-0.2\\-0.2\\0\\0\\0\\0\end{pmatrix}, \underline{\theta}\right] & \text{if } \frac{h}{W} \le 0.25 \\ \operatorname{linterp}\left[\begin{pmatrix}0.25\\0.5\end{pmatrix}, \begin{bmatrix}\operatorname{linterp}\left[\begin{pmatrix}10\,deg\\15\,deg\\20\,deg\\25\,deg\\30\,deg\\35\,deg\\45\,deg\\60\,deg\\90\,deg\end{pmatrix}, \begin{pmatrix}-0.7\\-0.5\\-0.3\\-0.2\\-0.2\\0\\0\\0\\0\end{pmatrix}, \underline{\theta}\right] \\ \operatorname{linterp}\left[\begin{pmatrix}10\,deg\\15\,deg\\20\,deg\\25\,deg\\30\,deg\\35\,deg\\45\,deg\\60\,deg\\90\,deg\end{pmatrix}, \begin{pmatrix}-0.9\\-0.7\\-0.4\\-0.3\\-0.2\\-0.2\\0\\0\\0\end{pmatrix}, \underline{\theta}\right]\end{bmatrix}, \frac{h}{W}\right] & \text{if } 0.25 < \frac{h}{W} \le 0.5 \\ \operatorname{linterp}\left[\begin{pmatrix}0.5\\1.0\end{pmatrix}, \begin{bmatrix}\operatorname{linterp}\left[\begin{pmatrix}10\,deg\\15\,deg\\20\,deg\\25\,deg\\30\,deg\\35\,deg\\45\,deg\\60\,deg\\90\,deg\end{pmatrix}, \begin{pmatrix}-0.9\\-0.7\\-0.4\\-0.3\\-0.2\\-0.2\\0\\0\\0\end{pmatrix}, \underline{\theta}\right] \\ \operatorname{linterp}\left[\begin{pmatrix}10\,deg\\15\,deg\\20\,deg\\25\,deg\\30\,deg\\35\,deg\\45\,deg\\60\,deg\\90\,deg\end{pmatrix}, \begin{pmatrix}-1.3\\-1.0\\-0.7\\-0.5\\-0.3\\-0.2\\0\\0\\0\end{pmatrix}, \underline{\theta}\right]\end{bmatrix}, \underline{\theta}\right] & \text{if } 0.5 < \frac{h}{W} < 1.0 \\ \operatorname{linterp}\left[\begin{pmatrix}10\,deg\\15\,deg\\20\,deg\\25\,deg\\30\,deg\\35\,deg\\45\,deg\\60\,deg\\90\,deg\end{pmatrix}, \begin{pmatrix}-1.3\\-1.0\\-0.7\\-0.5\\-0.3\\-0.2\\0\\0\\0\end{pmatrix}, \underline{\theta}\right] & \text{otherwise} \end{cases}$$

$$C_{p_roof_Windward1_\Gamma} = -0.2$$

$$C_{p_roof_Windward2_\Gamma} := \begin{cases} \text{linterp}\left[\begin{pmatrix}10\text{deg}\\15\text{deg}\\20\text{deg}\\25\text{deg}\\30\text{deg}\\35\text{deg}\\45\text{deg}\\60\text{deg}\\90\text{deg}\end{pmatrix},\begin{pmatrix}-0.18\\0.0\\0.2\\0.3\\0.3\\0.4\\0.4\\0.01\cdot\underline{\theta}\\0.01\cdot\underline{\theta}\end{pmatrix}\right],\underline{\theta} & \text{if } \frac{h}{W}\le 0.25 \\ \text{linterp}\left[\begin{pmatrix}0.25\\0.5\end{pmatrix},\left[\begin{pmatrix}10\text{deg}\\15\text{deg}\\20\text{deg}\\25\text{deg}\\30\text{deg}\\35\text{deg}\\45\text{deg}\\60\text{deg}\\90\text{deg}\end{pmatrix},\begin{pmatrix}-0.18\\0.0\\0.2\\0.3\\0.3\\0.4\\0.4\\0.01\cdot\underline{\theta}\\0.01\cdot\underline{\theta}\end{pmatrix}\right],\left[\begin{pmatrix}10\text{deg}\\15\text{deg}\\20\text{deg}\\25\text{deg}\\30\text{deg}\\35\text{deg}\\45\text{deg}\\60\text{deg}\\90\text{deg}\end{pmatrix},\begin{pmatrix}-0.18\\-0.18\\0.0\\0.2\\0.2\\0.3\\0.4\\0.01\cdot\underline{\theta}\\0.01\cdot\underline{\theta}\end{pmatrix}\right]\right],\frac{h}{W} & \text{if } 0.25<\frac{h}{W}\le 0.5 \\ \text{linterp}\left[\begin{pmatrix}0.5\\1.0\end{pmatrix},\left[\begin{pmatrix}10\text{deg}\\15\text{deg}\\20\text{deg}\\25\text{deg}\\30\text{deg}\\35\text{deg}\\45\text{deg}\\60\text{deg}\\90\text{deg}\end{pmatrix},\begin{pmatrix}-0.18\\-0.18\\0.0\\0.2\\0.2\\0.3\\0.4\\0.01\cdot\underline{\theta}\\0.01\cdot\underline{\theta}\end{pmatrix}\right],\left[\begin{pmatrix}10\text{deg}\\15\text{deg}\\20\text{deg}\\25\text{deg}\\30\text{deg}\\35\text{deg}\\45\text{deg}\\60\text{deg}\\90\text{deg}\end{pmatrix},\begin{pmatrix}-0.18\\-0.18\\-0.18\\0.0\\0.2\\0.2\\0.3\\0.01\cdot\underline{\theta}\\0.01\cdot\underline{\theta}\end{pmatrix}\right]\right],\underline{\theta} & \text{if } 0.5<\frac{h}{W}<1.0 \\ \text{linterp}\left[\begin{pmatrix}10\text{deg}\\15\text{deg}\\20\text{deg}\\25\text{deg}\\30\text{deg}\\35\text{deg}\\45\text{deg}\\60\text{deg}\\90\text{deg}\end{pmatrix},\begin{pmatrix}-0.18\\-0.18\\-0.18\\0.0\\0.2\\0.2\\0.3\\0.01\cdot\underline{\theta}\\0.01\cdot\underline{\theta}\end{pmatrix}\right],\underline{\theta} & \text{otherwise} \end{cases}$$

$C_{p_roof_Windward2_\Gamma} = 0.22$

Wind Normal to ridge $C_{p_roof_windward} := \begin{pmatrix} C_{p_roof_Windward2_\Gamma} \\ C_{p_roof_Windward1_\Gamma} \end{pmatrix}$ $C_{p_roof_windward} = \begin{pmatrix} 0.22 \\ -0.2 \end{pmatrix}$

$C_{p_roof_leeward_\Gamma} = -0.6$

Wind Parallel to ridge Figure 6-6

Distance from windward wall horizontally

for 0 to h/2 for h/2 to h for h to 2h for 2h+

$C_{p_roof_llA} := \begin{pmatrix} -0.18 \\ -0.9 \end{pmatrix}$ $C_{p_roof_llB} := \begin{pmatrix} -0.18 \\ -0.9 \end{pmatrix}$ $C_{p_roof_llC} := \begin{pmatrix} -0.18 \\ -0.5 \end{pmatrix}$

$G = 0.9$ $C_{p_roof_llD} := \begin{pmatrix} -0.18 \\ -0.3 \end{pmatrix}$

2. Shear Load per wall: (Roof loads plus half of wall loads)

Note: internal pressures cancel and therefore are ignored in calculating total shear

Wind Perpendicular to Ridge:

MWFRS Roof Pressure $MWFRS_{roof_\Gamma} := q_h \cdot \left| G \cdot C_{p_roof_windward_0} \right| - \left| G \cdot C_{p_roof_leeward_\Gamma} \right|$

MWFRS Wall Pressure $MWFRS_{wall_\Gamma} := q_h \cdot \left| G \cdot C_{p_wall_windward} - G \cdot C_{p_wall_leeward} \right|$

$MWFRS_{roof_\Gamma} = 23.02 psf$ $MWFRS_{wall_\Gamma} = 36.39 psf$

$q_h = 31.22 psf$

Total Shear from Roof $VPA_{_\Gamma} \cdot MWFRS_{roof_\Gamma} = 12085.39 lbf$

$Shear_{_\Gamma_roof} := VPA_{_\Gamma} \cdot MWFRS_{roof_\Gamma}$

Total Shear from Wall $VPA_{wall_\Gamma} \cdot MWFRS_{wall_\Gamma} = 9825.42 lbf$

$Shear_{_\Gamma_wall} := VPA_{wall_\Gamma} \cdot MWFRS_{wall_\Gamma}$

Total shear Γ $Shear := VPA_{wall_\Gamma} \cdot MWFRS_{wall_\Gamma} + VPA_{_\Gamma} \cdot MWFRS_{roof_\Gamma}$

$Shear_{_\Gamma} := \max\left(VPA_{wall_\Gamma} \cdot MWFRS_{wall_\Gamma} + VPA_{_\Gamma} \cdot MWFRS_{roof_\Gamma} \right)$

$Shear = 21910.8 lbf$

Wind Parallel to Ridge:

Total Shear from Wall $Shear_{ll_wall} := \left(VPA_{wall_ll} + VPA_{ll} \right) \cdot q_h \cdot \left| G \cdot C_{p_wall_windward} - G \cdot C_{p_wall_leeward} \right|$

$Shear_{ll_wall} = 9688.96 lbf$

$VPA_{wall_ll} = 266.25 ft^2$

Total Shear II $Shear_{ll} := Shear_{ll_wall}$

3. Allowable shear resistance from NDS Supplement for structural use panel shear wall and diaphragm
Follow example 38 page 426 from NDS 2005 examples book

Exterior Surface: 3/8" OSB $t_{OSB} = 0.375in$
Interior Surface: 1/2" Gypsum Blocked construction

Nail Size: 8d common Nail spacing: 6"/12"

$\Delta_{stud} = \begin{pmatrix} 12 \\ 16 \end{pmatrix} in$ Spacing of studs in wall

$Shear_{OSBallowable} := \frac{560}{2} \cdot \frac{lbf}{ft}$ Table 4.3A NDS 2005 Wind and Seismic Special Design provisions 3/8" sheathing with 6d nails at 6" at edges page 26

$Shear_{DryWallallowable} := \frac{310}{2} \cdot \frac{lbf}{ft}$ Table 4.3B NDS 2005 Wind and Seismic Special Design Provisions 1/2 in drywall page 27 with S nails spaced at 4 in on edges and 16 in the field

$Shear_{allowable} := Shear_{OSBallowable} + Shear_{DryWallallowable}$

$L_{shearMin_\Gamma} := \frac{Shear_{\Gamma}}{2Shear_{allowable}}$ $L_{shearMin_\Gamma} = 25.18\,ft$ assume half the loads are transferred to interior walls

$L_{shearMin_ll} := \frac{\max(Shear_{ll})}{2Shear_{allowable}}$ $L_{shearMin_ll} = 11.14\,ft$

Actual length available for shear walls:

$L_{shearwall_Actual_\Gamma} := (30 \;\; 24 \;\; 18 \;\; 20 \;\; 8)^{T} \cdot ft$ $\sum L_{shearwall_Actual_\Gamma} = 100\,ft$

$L_{shearwall_Actual_ll} := (4 \;\; 4 \;\; 10 \;\; 4 \;\; 24 \;\; 10 \;\; 4 \;\; 4 \;\; 4 \;\; 4)^{T} \cdot ft$ $\sum L_{shearwall_Actual_ll} = 72\,ft$

$Wood_Shear := \left| \begin{array}{l} PASS \;\; if \left(\sum L_{shearwall_Actual_\Gamma} > L_{shearMin_\Gamma} \right) \cdot \left(\sum L_{shearwall_Actual_ll} > L_{shearMin_ll} \right) \\ FAIL \;\; otherwise \end{array} \right.$

$Wood_Shear = 1$

4. Shear of Anchor Bolts

$t_{wall} := 8in$ use 8 inches according to the FBC chapter 4 foundations R403.1.1

$F_{T_anchor} := 20000psi$ Treat anchor bolt like a common A307 bolt (similar to a A36 steel value) with regards to steel properties

$d_{bolt} := \frac{5}{8}in$ allowable tensile stress

$F_{V_anchor} := 10000psi$ Allowable shear stress in a A307 Bolt

$C_{.t} := 1.0$ temperature service factor

$C_{others} := 1.0$ bunch of other factors for end grain, toenail, etc. which are all 1.0

$C_g := 1.0$ Group Action Factor: fasteners are several feet apart and therefore behave as single fasteners

$Shear_{\underline{\Gamma}} := 2Shear_{\underline{\Gamma}_wall} + Shear_{\underline{\Gamma}_roof}$

$Shear_{\underline{\Gamma}} = 31736.23lbf$ Total Shear to be resisted

$$N_{bolts} := \frac{Shear_{\underline{\Gamma}}}{F_{V_anchor} \cdot \frac{d_{bolt}^{2}}{4} \cdot 3.14}$$

$N_{bolts} = 10.35$

$$\underline{\Delta}_{boltshear} := floor\left[\frac{2\frac{|W - o + L - 2 \cdot o_g|}{ft}}{ceil(N_{bolts})}\right]$$

$1ft\underline{\Delta}_{boltshear} = 16\ ft$

$$F_{v_actual} := \frac{max(Shear_{\underline{\Gamma}})}{ceil(N_{bolts}) \cdot \frac{d_{bolt}^{2}}{4} \cdot 3.14}$$

$F_{v_actual} = 9408.77psi$ actual shear stress per anchor

Check Anchor bolt pull out force from concrete. This occurs when walls receive maximum tension in the D+W load scenario. Assume one wall resists the uplift force (conservative)

$$F_{upallowBolt} := \frac{d_{bolt}^{2}}{4} \cdot 3.14 F_{T_anchor}$$

$F_{upallowBolt} = 6132.81lbf$ Capacity per Bolt

$$N_{anchorUP} := \frac{Axial_{DW} \cdot |L - 2 \cdot o_g|}{F_{upallowBolt}}$$

$N_{anchorUP} = 2.94$ Uplift force to design per anchor bolt

$$\Delta_{boltuplift} := floor\left(\frac{\frac{L - 2\cdot o_g}{ft}}{ceil\left(N_{anchorUP}\right)}\right) \qquad ft\cdot\Delta_{boltuplift} = 20\,ft$$

minimum spacing for uplift

$$F_{up_anchor} := \Delta_{boltuplift}\cdot Axial_{DW} \qquad F_{up_anchor} = 6008.85\frac{1}{ft}\,lbf$$

Tensile force in the anchor bolt

min spacing thus far

$$\Delta_{bolt} := min\left(\Delta_{boltuplift}, \Delta_{boltshear}\right) \qquad \Delta_{bolt} = 16$$

shear in anchor at this stress

$$F_anchor_shear := max\left[\left[\frac{\Delta_{bolt}}{2\cdot\left(W - o + L - 2\cdot o_g\right)}\right]\cdot\frac{Shear_{\Gamma}}{\frac{d_{bolt}^{\,2}}{4}\cdot 3.14}\right] \qquad F_anchor_shear = 9199.69\frac{1}{ft}\,psi$$

Combined shear and tension in the bolt use Eliptical von misses criterion page 16.1-244 of AISC ignore reduction factors and use ASD shear and tension stress values

$$F_{t_allow} := \left[\left(\frac{F_{T_anchor}}{1000psi}\right)^2 - \left(\frac{F_{T_anchor}\cdot F_anchor_shear\cdot ft}{F_{V_anchor}\cdot 1000psi}\right)^2\right]^{0.5}\cdot 1000psi$$

allowable tensile force in the bolt

$$F_{t_allow} = 7839.82psi$$

Force per bolt revised

$$F_up_bolt_combined := \frac{d_{bolt}^{\,2}}{4}\cdot 3.14\cdot max\left(F_{t_allow}\right) \qquad F_up_bolt_combined = 2404.01lbf$$

Spacing revised

$$N_{anchor.UP} := \frac{Axial_{DW}\cdot\left(L - 2\cdot o_g\right)}{F_up_bolt_combined} \qquad N_{anchorUP} = 7.5$$

$$\Delta_{anhcor_bolt} := floor\left(\frac{\frac{L - 2\cdot o_g}{ft}}{ceil\left(N_{anchorUP}\right)}\right) \qquad ft\cdot\Delta_{anhcor_bolt} = 7\,ft$$

WALL DESIGN for Masonry Walls (ACI 530-99)

Masonry can be used instead of wood walls. FBC2004/7 specifies that chapters 1 and 2 from the ACI 530 code can be used to design masonry walls for allowable stress design. Assume that straps are embedded in a bond beam and that the masonry wall is partially grouted with a piece of rebar running down the middle of a CMU cell. Assume that the bond beam has 2 pieces of rebar running parallel to the eave of the dwelling at both the top and bottom of the bond beam. Assume that any tension due to uplift is taken by this vertical steel which is fully transmitted by the bond beam to the vertical rebar. Check the Masonry wall for shear, and the maximum compressive load. Vertical reinforcement is placed at the center of the wall. The wall is assumed to be unreinforced otherwise. The weight of the wall has been neglected since the applied loadings are small relative to the capacity of the wall (conservative in most cases). Use the same anchor bolt diameter and spacing from the wood design (conservative) to transmit the tensile force from the roof to the footings.

Assume 8" thick CMU units (7.625" nominal), each 16"(15.625 nominal)

$\Delta_{cmu} := \frac{16in}{2}$ $\Delta_{cmu} = 8\,in$ $d_{CMU} := 8in - .375in$ $d_{CMU} = 7.63in$

CMU grout spacing

$\Delta_{groutBar} := floor\left(\frac{\Delta_{bolt}\cdot ft}{\Delta_{cmu}}\right)\cdot\Delta_{cmu}$ $\Delta_{groutBar} = 16\,ft$

Insure that vertical rebar is placed in increments equal to half the length of a CMU unit

Vertical rebar properties-use the same as per wood construction from previous work

$\Delta_{groutBar.} := \Delta_{bolt}$

$\Delta_{groutBar} = 16$

$V_{rebar} := d_{bolt}$ $V_{rebar} = 0.63in$ use the same diameter of bar as per anchor bolt diameter

Masonry Wall Design Parameters

For loads Parallel to the wall face

$A_{CMU} := 30in^2$ Area of concrete unit. (smallest area CMU from Civil Eng Ref. Book by M. R. L 10th edition

$I_{yy} := 334in^4$ Moment of inertia of section

$S_y := 81in^3$

Masonry Properties

$f_m := 1500\cdot psi$ allowable compression stress of CMU with M or S mortar

$E_m := 900 \cdot f_m$ for fm of 1500 psi masonry

$E_m = 1.35 \times 10^6 \text{ psi}$

$r := 2.84\text{in}$

$P := Axial_{DLW_1}$ $P = -684.38 \frac{1}{\text{ft}} \text{ lbf}$ Axial Force per unit length of wall

$e_{axial} := 0\text{in}$

$P_e := \frac{3.14^2 \cdot E_m \cdot I_{yy}}{h^2} \cdot \left[1 - 0.577 \cdot \left(\frac{e_{axial}}{r}\right)\right]^3$ $P_e = 164288.71 \text{lbf}$

$Status_{AxialMasonry} := \begin{cases} 1 & \text{if } P \cdot 1\text{ft} \le \frac{P_e}{4} \\ 0 & \text{otherwise} \end{cases}$ $Status_{AxialMasonry} = 1$

$f_a := \frac{P \cdot 1\text{ft}}{A_{CMU}}$ $f_a = -22.81\text{psi}$

$F_a := \begin{cases} \frac{1}{4} \cdot f_m \cdot \left[1 - \left(\frac{h}{140 \cdot r}\right)^2\right] & \text{if } \frac{h}{r} \le 99 \\ \frac{1}{4} \cdot f_m \cdot \left(\frac{70 \cdot r}{h}\right)^2 & \text{otherwise} \end{cases}$ $F_a = 310.81\text{psi}$

$F_{b.} := \frac{1}{3} \cdot f_m$ $F_b = 500\text{psi}$

$f_b := \frac{M_{wallMax}}{S_y}$ $f_b = 89.14\text{psi}$

Interaction equation:

$Status_{Masonry} := \begin{cases} 1 & \text{if } \left(\frac{|f_a|}{F_a} + \frac{|f_b|}{F_b}\right) \le 1 \\ 0 & \text{otherwise} \end{cases}$ $\left(\frac{|f_a|}{F_a} + \frac{|f_b|}{F_b}\right) = 0.25$ $Status_{Masonry} = 1$

Maximum spacing of reinforcement due to wind load

$f_{btension} := 30\text{psi}$ Allowable tensile strength in masonry assuming partially grouted units S mortar

$\Delta_{steel} := \sqrt{\frac{12 \cdot f_{btension} \cdot S_y}{-p_{wall_0} \cdot \text{ft}}}$ Assuming fixed-fixed end conditions $p_{wall} = \begin{pmatrix} -74.71 \\ 61.25 \end{pmatrix} \text{psf}$

$\Delta_{.steel} := \text{floor}\left(\frac{\Delta_{steel}}{8 \cdot \text{in}}\right) \cdot 8 \cdot \text{in}$ round down to nearest 8" multiple (dist between cells) $\Delta_{steel} = 68.44\text{in}$ $\Delta_{steel} = 5.7 \text{ ft}$

Check shear in the masonry wall

Shear Force per unit length of wall

Available wall length

$\sum L_{shearwall_Actual_\Gamma} = 100\,ft$

$\sum L_{shearwall_Actual_ll} = 72\,ft \quad \max\left|Shear_{ll}\right| = 9688.96\,lbf \quad Shear_{\Gamma} = 31736.23\,lbf$

Maximum force per unit length of wall

Shear in the wall. Design the section as a wall with net tension page 69-12 in Civil Eng. Ref. Manual for PE

$$V := \max\left(\frac{\max\left|Shear_{ll}\right|}{\sum L_{shearwall_Actual_ll}}, \frac{Shear_{\Gamma}}{\sum L_{shearwall_Actual_\Gamma}}\right)\cdot 12in \qquad V = 317.36\,lbf$$

$$f_v := \frac{V}{d_{CMU}\cdot 12in} \qquad f_v = 3.47\,psi$$

$$F_{v.} := \begin{cases} \frac{1}{3}\cdot\left(4 - \frac{M_{wallMax}}{V\cdot d_{CMU}}\right)\cdot\left(\frac{f_m}{psi}\right)^{0.5}\cdot psi & \text{if } \frac{M_{wallMax}}{V\cdot d_{CMU}} < 1 \\ \left(\frac{f_m}{psi}\right)^{0.5}\cdot psi & \text{otherwise} \end{cases} \qquad F_v = 175\,psi$$

$$Status_{ShearMasonry} := \begin{cases} 1 & \text{if } f_v \le F_v \\ 0 & \text{otherwise} \end{cases} \qquad Status_{ShearMasonry} = 1$$

Foundation Design: Sliding and Overturning

$wood \equiv 0$

$masonry \equiv 1$

Anchor bolts have been designed to resist all sliding and overturning forces

Maximum spacing of reinforcement due to wind load

$f_{btension} := 30psi$ Allowable tensile strength in masonry assuming partially grouted units S mortar

$$\Delta_{steel} := \sqrt{\frac{12\cdot f_{btension}\cdot S_y}{-p_{wall_0}\cdot ft}}$$ Assuming fixed-fixed end conditions

$$p_{wall} = \begin{pmatrix} -44.57 \\ 34.46 \end{pmatrix} psf$$

$\Delta_{.steel} := floor\left(\frac{\Delta_{steel}}{8\cdot in}\right)\cdot 8\cdot in$ round down to nearest 8" multiple (dist between cells)

$\Delta_{steel} = 7.33\,ft$ $\Delta_{steel} = 88\,in$

SUMMARY:

$\text{Status}_{\text{sheath}} = 1$

$\text{Status}_{\text{sheathshear}} = 1$

$\text{Status}_{\text{truss}} = 1$

Use Minimum Spacing of 8d ring shank nails at 6"/12"

Use worst case of MWFRS as a representative load for the straps.

$R_{.design} := \max\left(\text{Strap}_2, \text{Strap}_3, \text{Strap}_4, \text{Strap}_5, \text{Strap}_6, \text{Strap}_7\right)$

$R_{design} = 762.88\,\text{lbf}$

$\text{Status}_{\text{panelFlex}} = 1$

$\text{Status}_{\text{sheathshear}} = 1$

$\text{Wood_Bending2x4} = 1$

$\text{Wood_Bending2x6} = 1$

$\text{Wood_Bending2x8} = 1$

$\text{Wood_Shear} = 1$

$\text{Status}_{\text{axial_2x4}} = 1$

$\text{Status}_{\text{axial_2x6}} = 1$

$\text{Status}_{\text{axial_2x8}} = 1$

$\text{ft} \cdot \underline{\Delta}_{\text{anhcor_bolt}} = 7\,\text{ft}$

$\text{Status}_{\text{ShearMasonry}} = 1$

$\text{Status}_{\text{AxialMasonry}} = 1$

$\text{Wood_Shear} = 1$

$\text{Status}_{\text{Masonry}} = 1$

Appendix E. Example Individual Building Analysis Reports

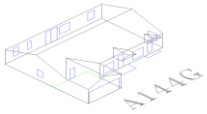
This appendix contains example reports produced from the HURLOSS analysis of individual buildings. The buildings correspond to Building Model A144G (Model Index 18) in Table 2-6. Two reports are included, corresponding to:

1. Weak house – shingle roof cover
2. Strong house – tile roof cover

The weak house corresponds to non-FBC, deck A, toe-nails, no opening protection, other window leakiness, and other soffits. The strong house corresponds to RBC, roof deck C, strap, hurricane protection, casement windows, and wood soffits.

Each report consists of 14 pages and contains the basic information on the building, model number, location, and simulated wind climate. The damage plots show key information on building component performance. All reports are for Location 13 (Fort Myers), Terrain B.

HurReport - Single Family Residential



Building Description

Year: 2008
Stories: 1

		Resistance
Primary Roof Shape:	Gable	NA
Roof Cover: (ft-lbs)	Curved Tiles	26.1
SWR:	No	
Roof/Wall (lbs) Connection:	Toe Nail	550
Roof Deck:	Plywood	54.6
Roof Deck (psf) Attachment:	6d/6.00/12.00/6.00	
Wall (psf) Construction:		/

Type	*Plan*	*Roof*	*Wall*	*Fen*	*Glazing*
Area (sf)	2406	2600	2218	394	244
Percent	NA	NA	NA	18%	11%

Protection Level	***Area** (sf)*	***Percent ** **
050 ft-lb @5%	188	8%
243 ft-lb @5%	56	3%

* percent of wall area for fens and percent of roof area for skylights.

Fen:	*Windows*	*Doors*	*Sliders*	*Garage*	*Skylights*
Cnt:	9	1	1	1	0

Program Parameters

Hurdam Directories:

Base: \runs
Program: \Programs\

Loss Directories:

Program: \Programs

Version:

HURSIM:		HURLOSS:	
HURDAM:		MitCost:	2.6
RESCOMLOSS:	19	HurReport:	1.2

Wind Climate

Num of Year Sim: 500,000
Weighted: Yes
Sim File: \WindClimateData\SIMW00013.dat

			Mean		
Type	*Min*	*Max*	Azmth	*Sim*	*v^2*
Missile: R	1.00	1.00	1.00	1.00	1.00
Missile: C	0.00	0.00	0.00	0.00	0.00
Terrain:	0.35	0.35	0.35	0.35	0.35

Num Sim Per Storm: 30
100 Yr Wind Speed: 121 mph
250 Yr Wind Speed: 131 mph
1000 Yr Wind Speed: 147 mph
Annual Occ. Rate:
Latitude (deg): 27.0100
Longitude (deg): 82.3700
Orientation:
Inland Distance(km):
Location: Random

Economic Description

	Value	*Cap*
Building:	$165,206.00	1.25
Contents:	$82,603.00	1.00
ALE:	$33,041.20	1.00
Deductible:	0/3304/8260	

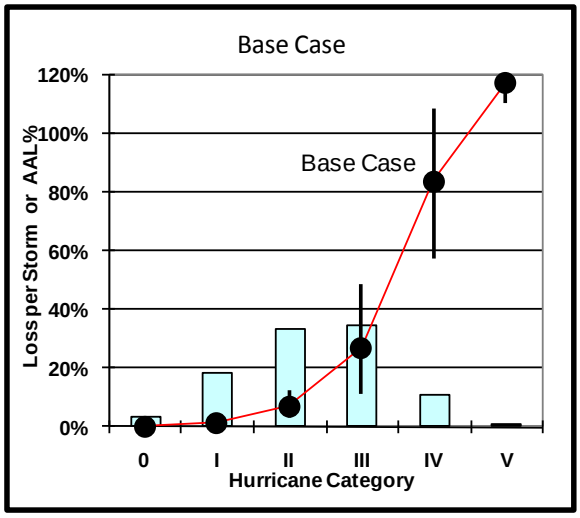
Cap Cont Cov: 0.5
Cap ALE Cov: 0.2
OHP: 1.2
R&R: 1.25

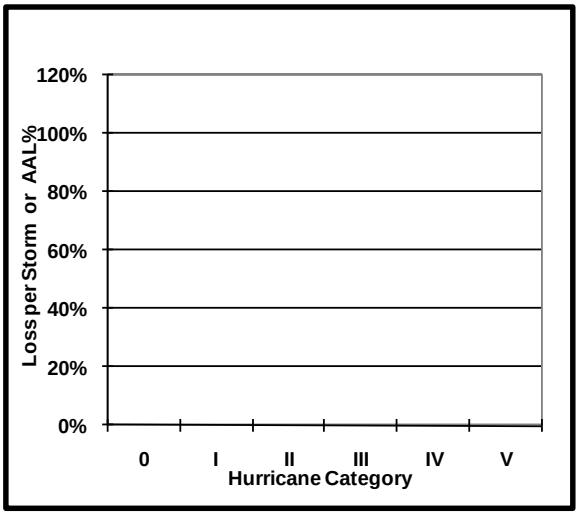
Global Results: Base Case

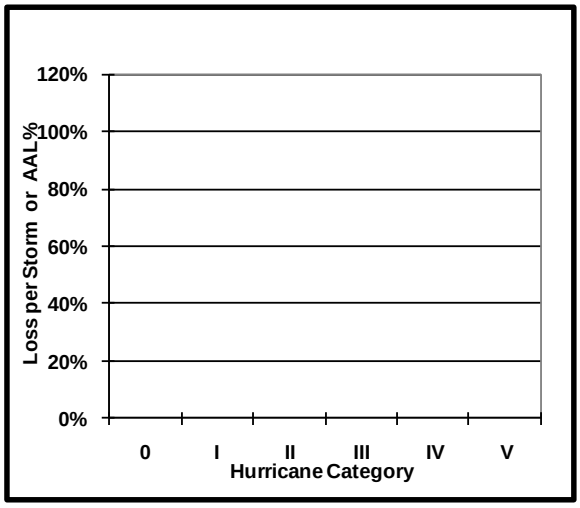
Average Damage State:
Ground Up AAL:
Ground Up Loss Cost:
PML 100 yr:
PML 250 yr:
PML 1000 yr:

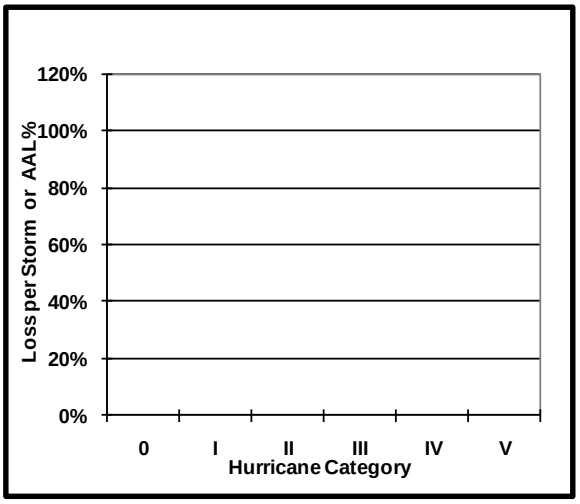
Vr: **Dflt** Tfact Roof: **Dflt** Tfact Fen Positive: **Dflt** Tfact Fen Negative: **Dflt**

LOSS CURVES FOR EACH PACKAGE - ONLY BASE CASE SHOWN





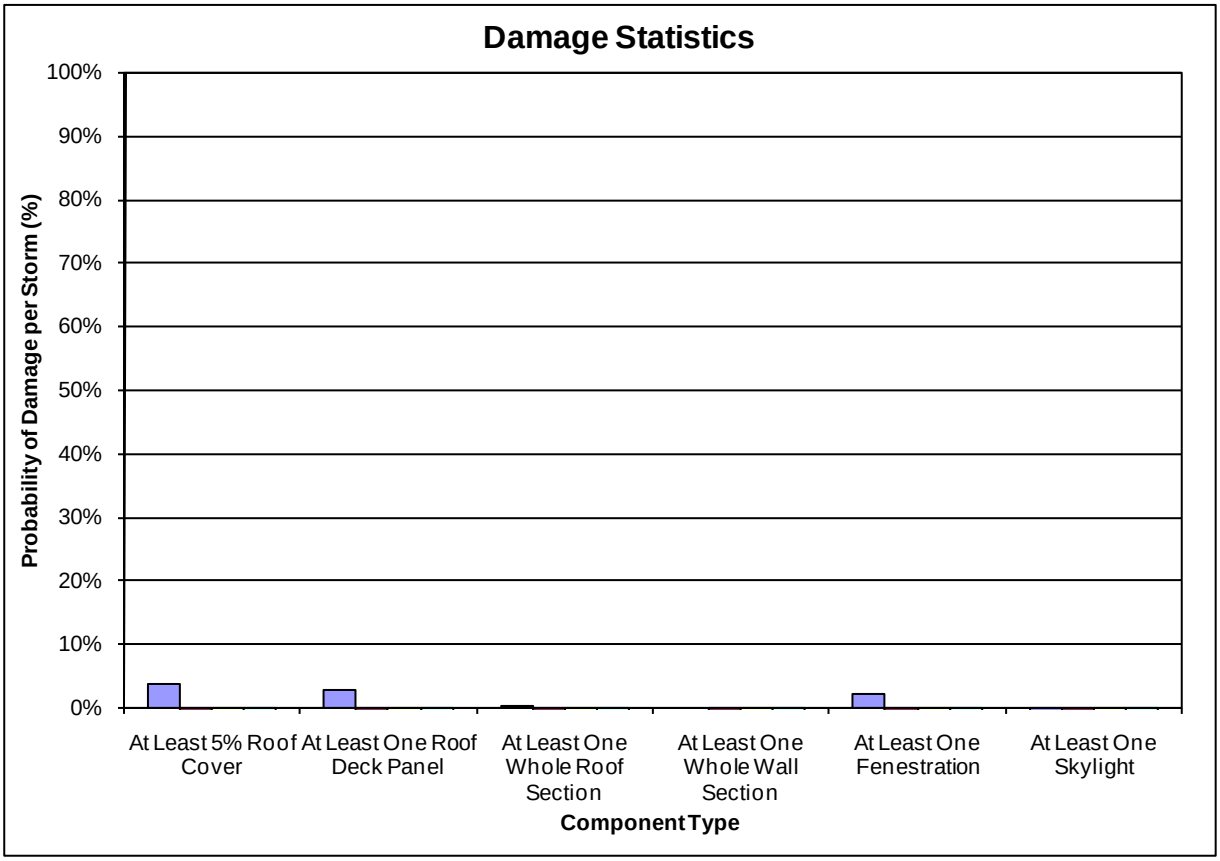


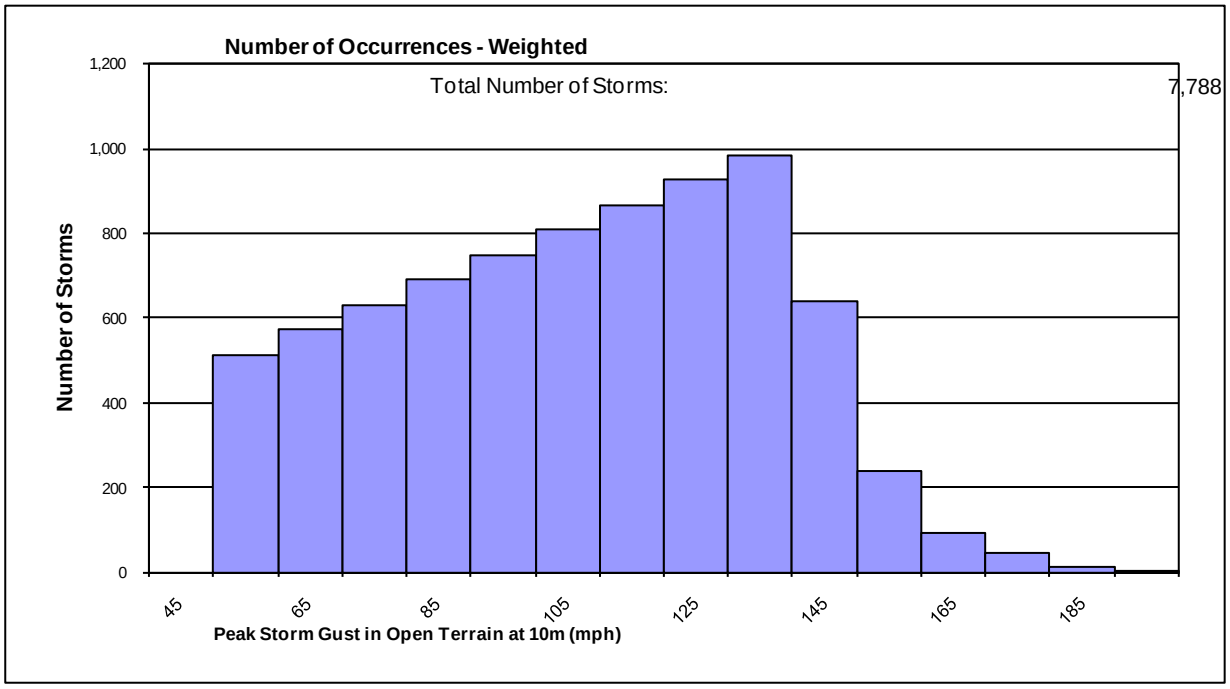


Building Characteristic	Resistances and Total Shutter Area			
	Base Case	Case 1	Case 2	Case 3
Roof Cover(ft-lbs)	26.100			
Roof Deck(psf)	54.600			
Secondary Water Resistance	No			
Roof/Wall Connection(lbs)	550.0			
Total Shutter Area / % of Wall Area	56 sqf / 0.03%			

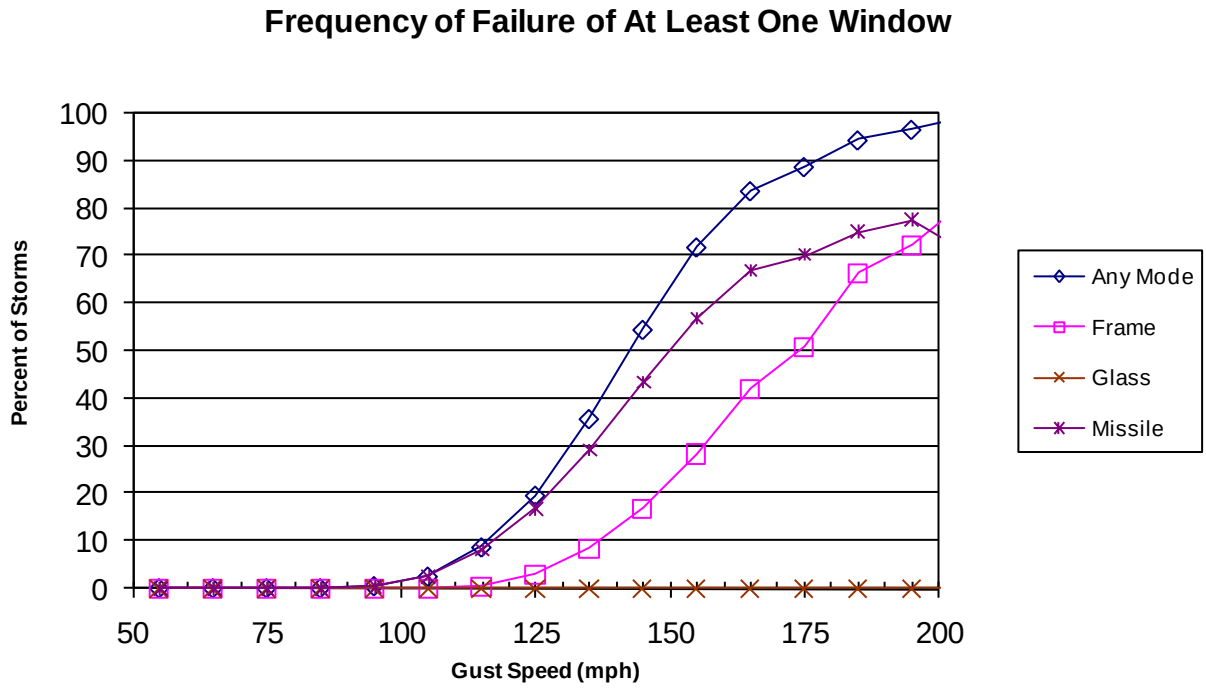
Global Results	Base Case	Case 1	Case 2	Case 3
Average Damage State	0.000			
Ground Up AAL	$0.00			
Ground Up Lost Cost	$0.00			
PML 100yr	$0.00			
PML 250yr	$0.00			
PML 1000yr	$0.00			

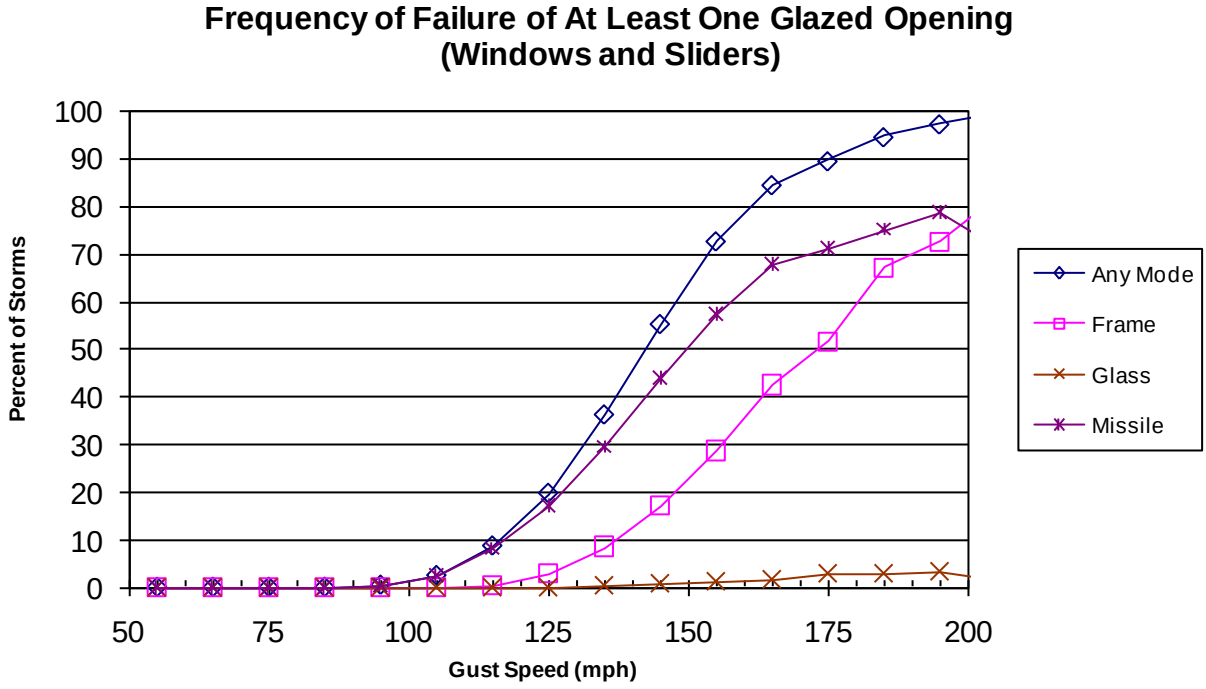
Cat.	Number of Storms
0	95,382
I	24,519
II	8,582
III	2,303
IV	232
V	11
Total	131,029



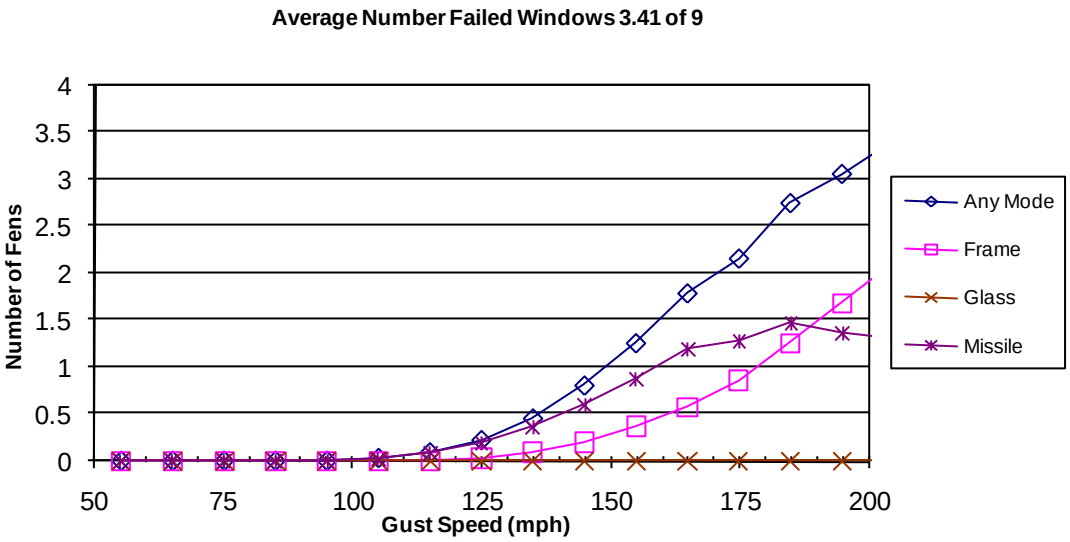


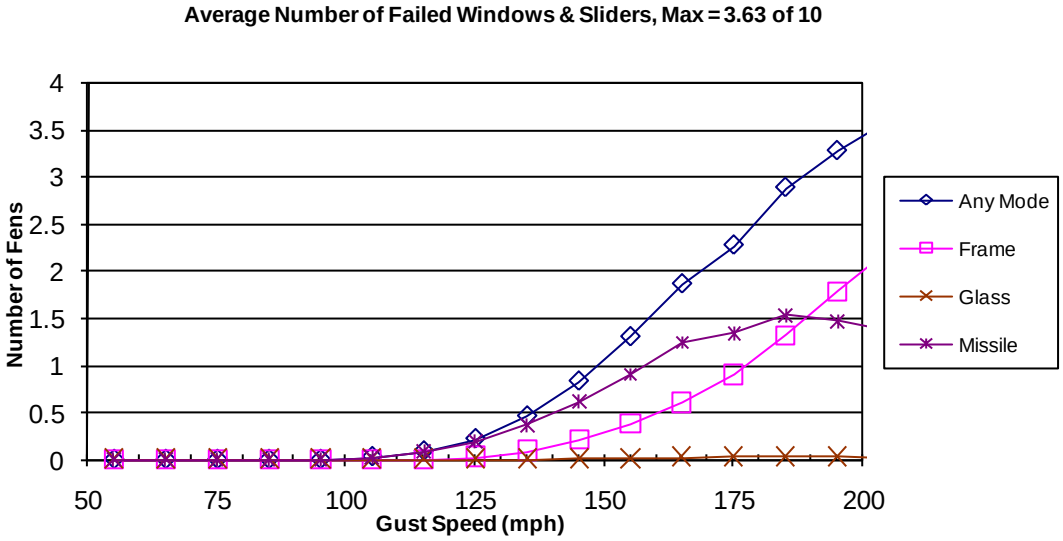
Damage Stats and Number of Storms



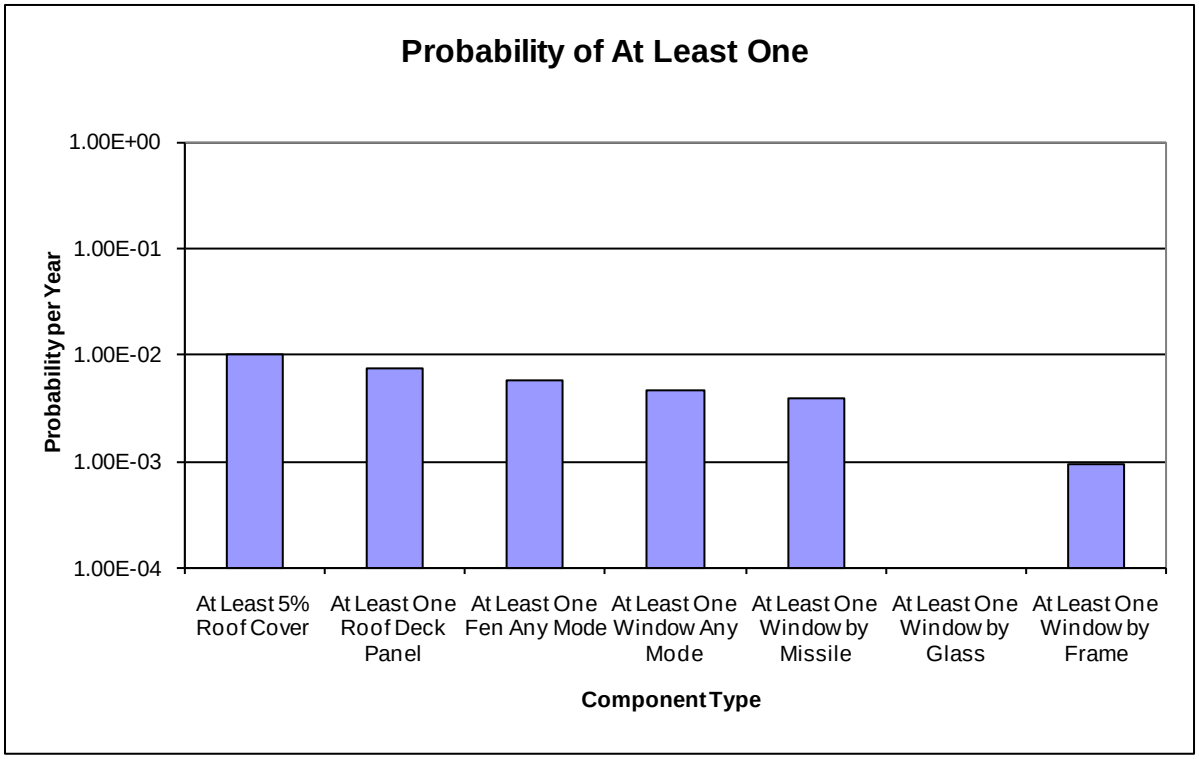


Frequency of Fenestration Failure

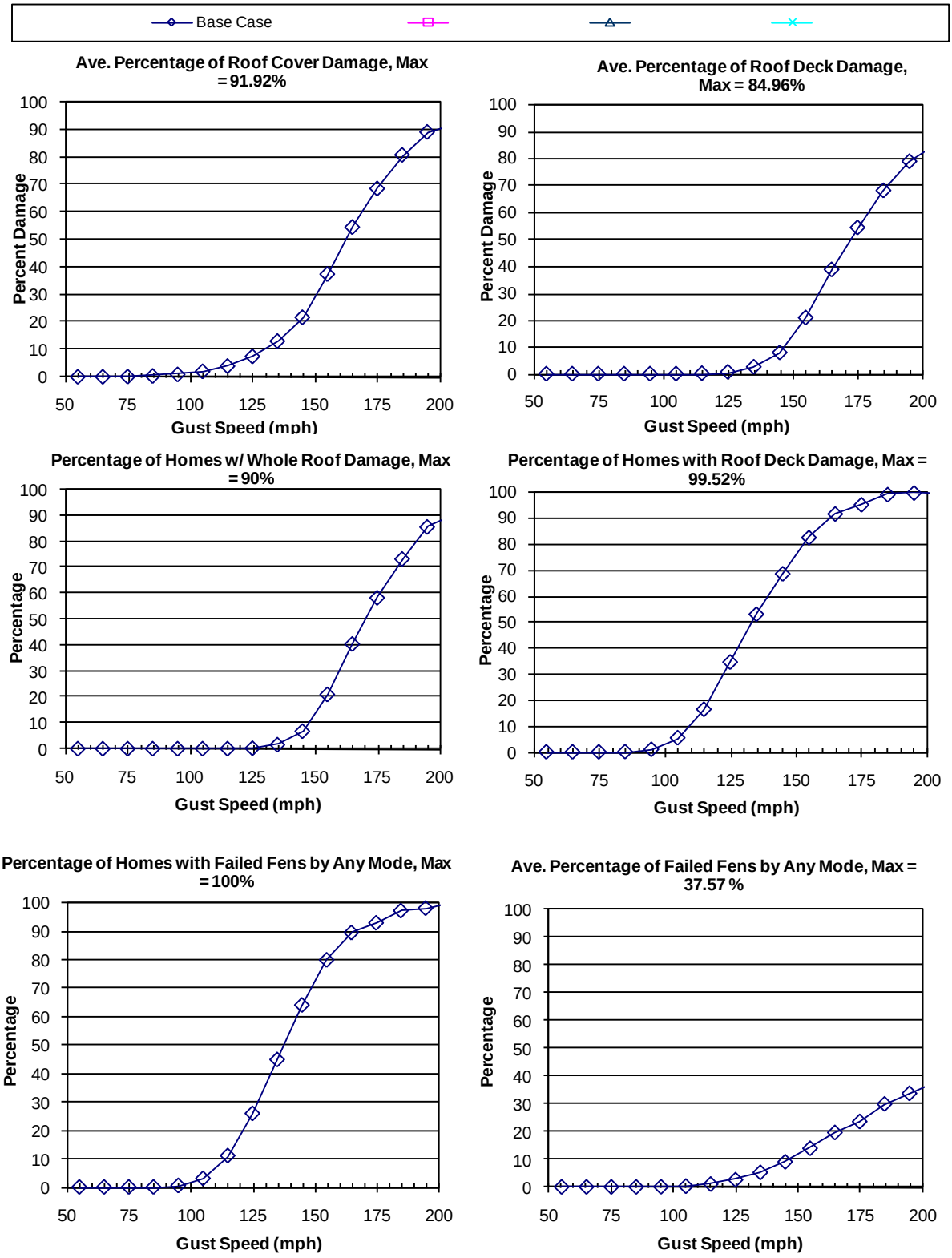




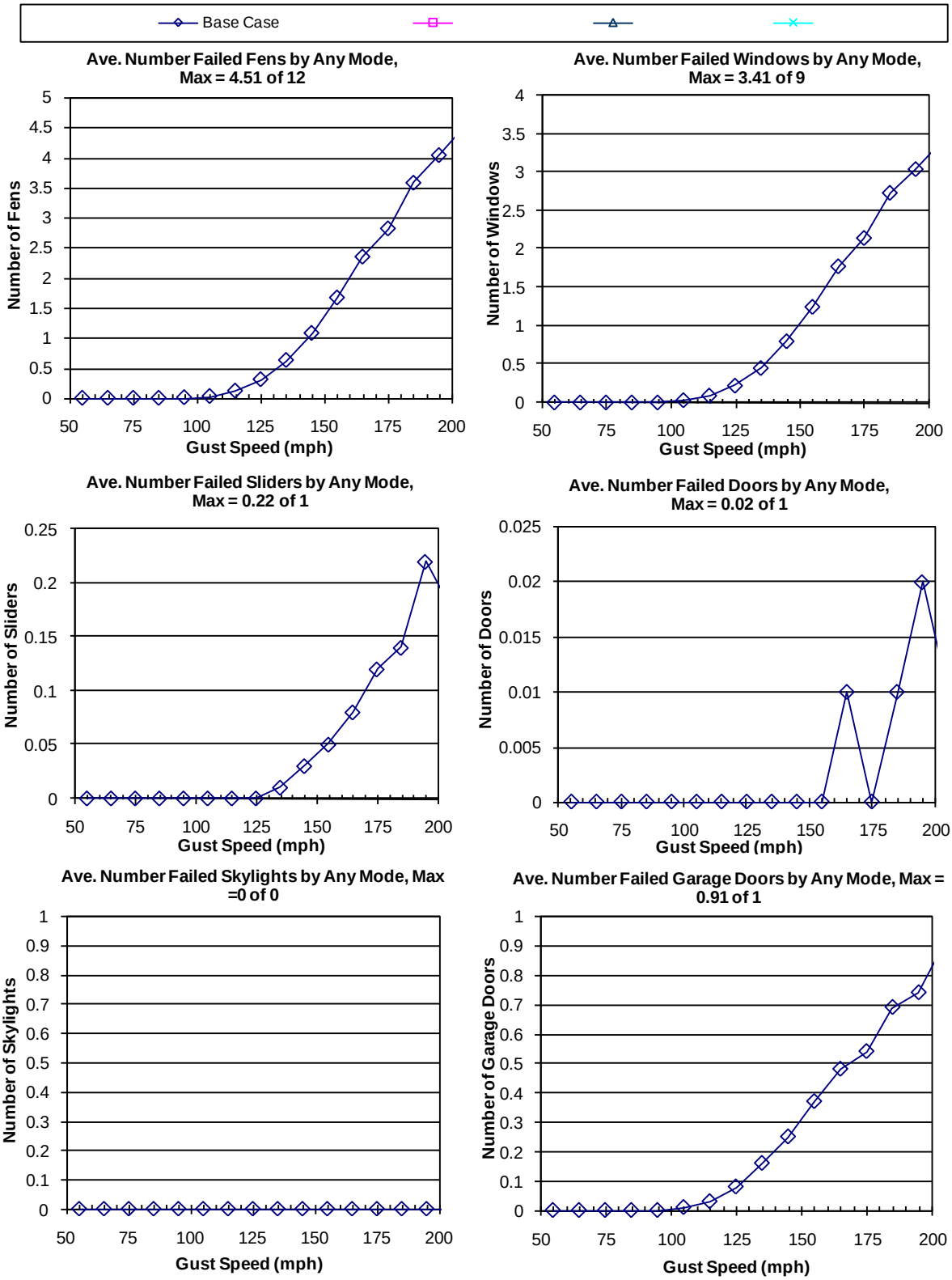
Average Number of Fenestration Failures



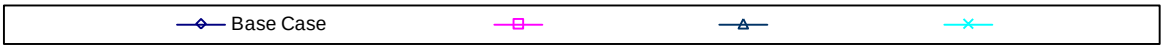
Probability of "At Least One" Damage

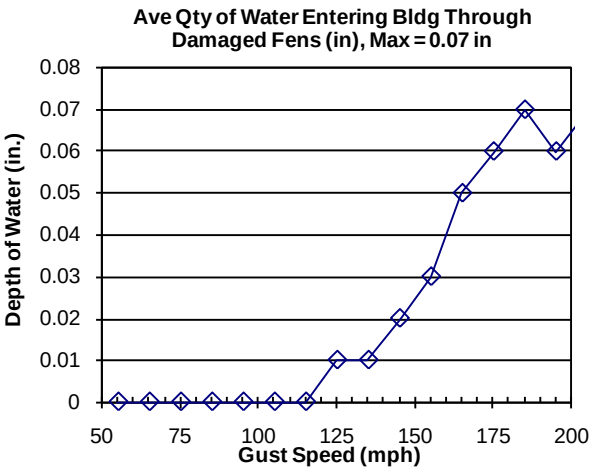

Base Case
Ave. Percentage of Roof Cover Damage, Max = 91.92%
Percent Damage
Gust Speed (mph)
Ave. Percentage of Roof Deck Damage, Max = 84.96%
Percent Damage
Gust Speed (mph)
Percentage of Homes w/ Whole Roof Damage, Max = 90%
Percentage
Gust Speed (mph)
Percentage of Homes with Roof Deck Damage, Max = 99.52%
Percentage
Gust Speed (mph)
Percentage of Homes with Failed Fens by Any Mode, Max = 100%
Percentage
Gust Speed (mph)
Ave. Percentage of Failed Fens by Any Mode, Max = 37.57 %
Percentage
Gust Speed (mph)

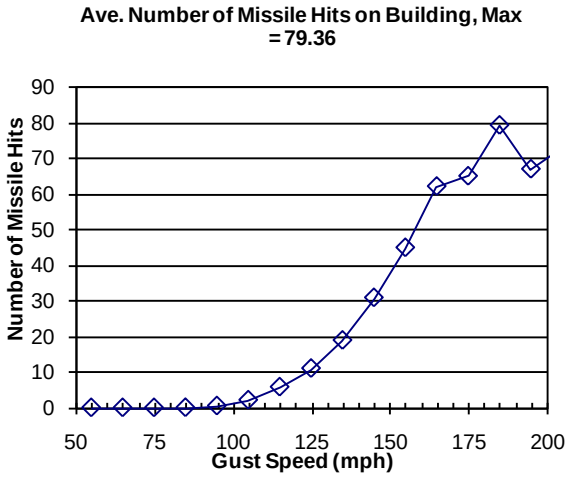
Roof Damage

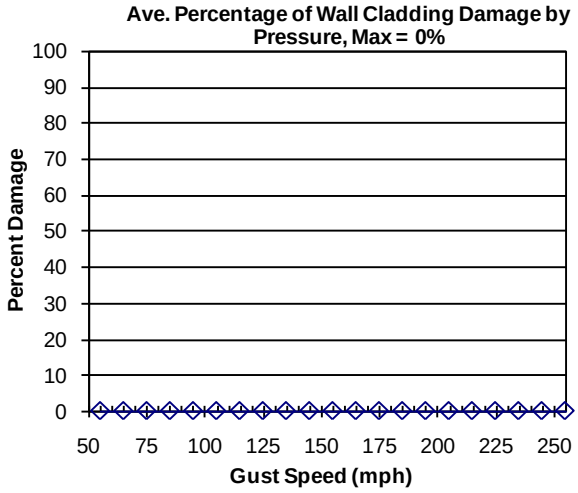


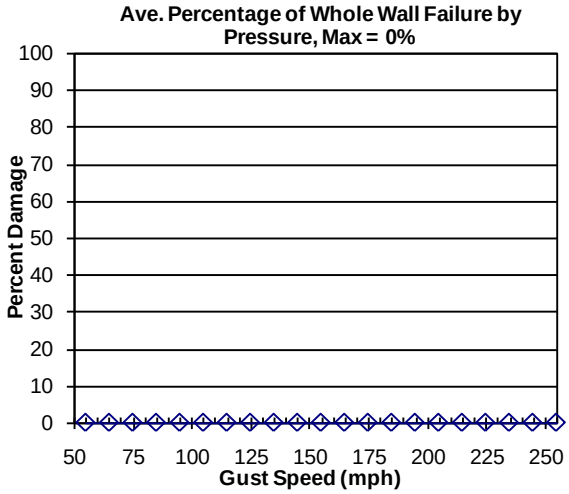
Fenestration Damage

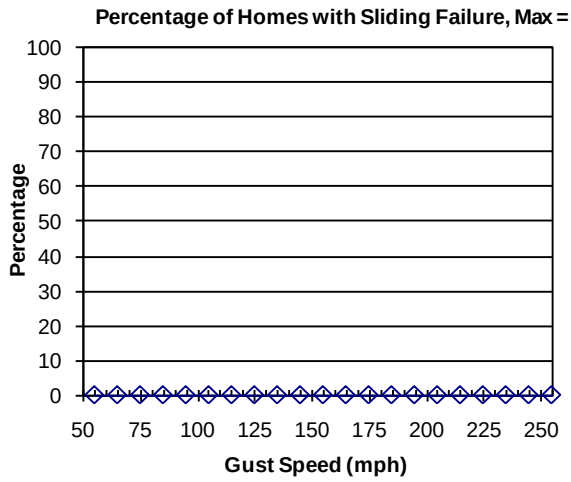


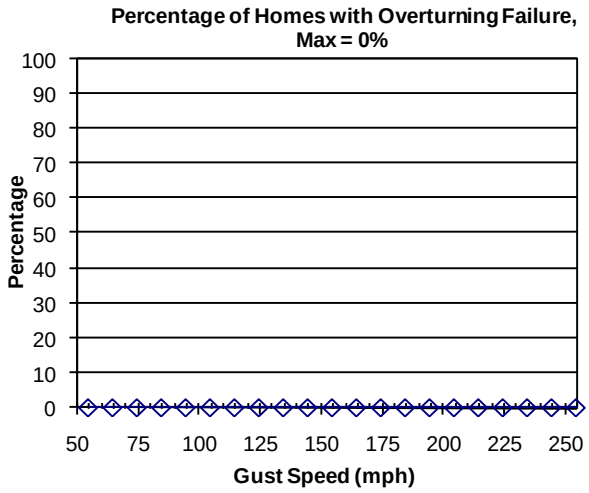




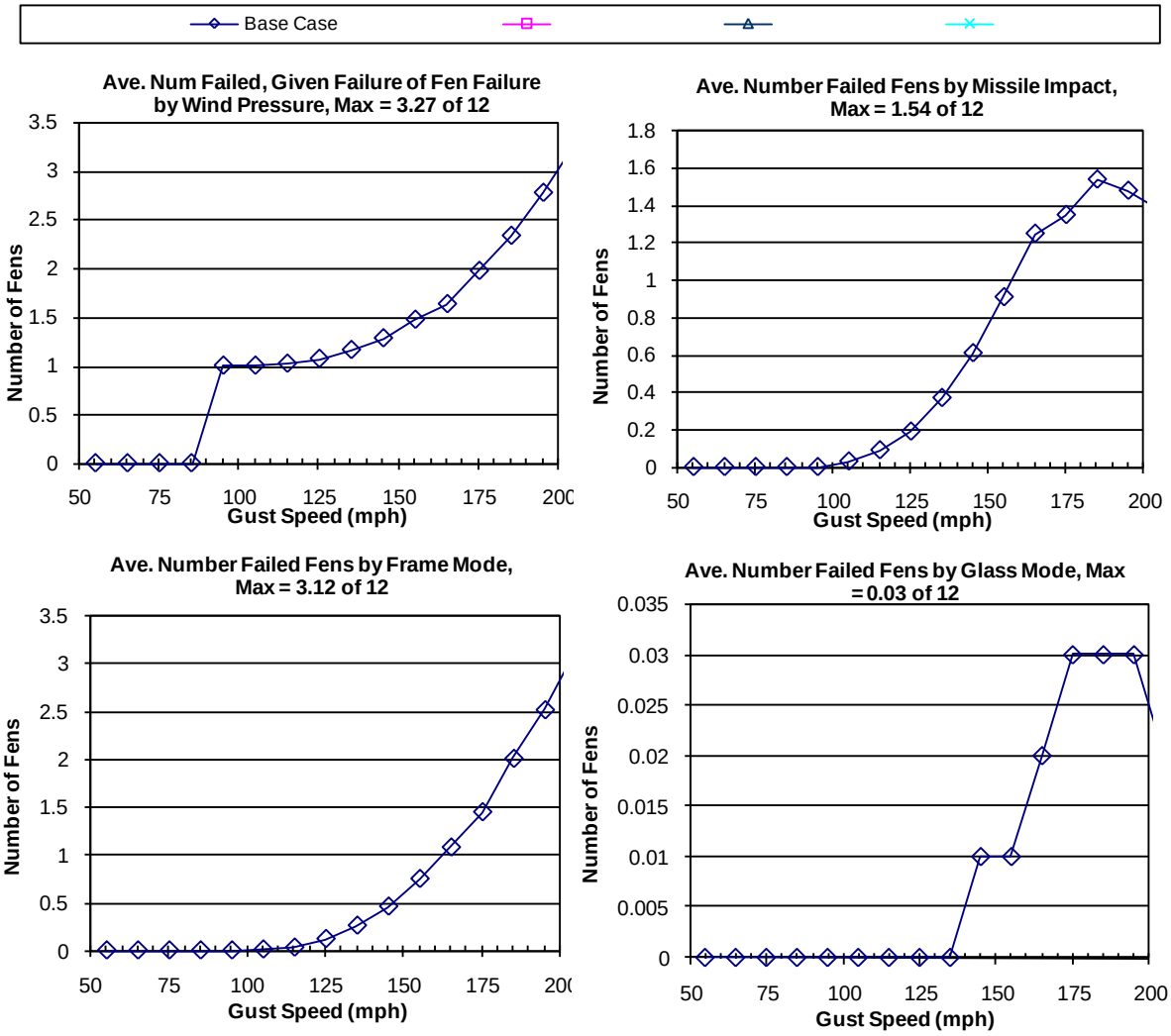




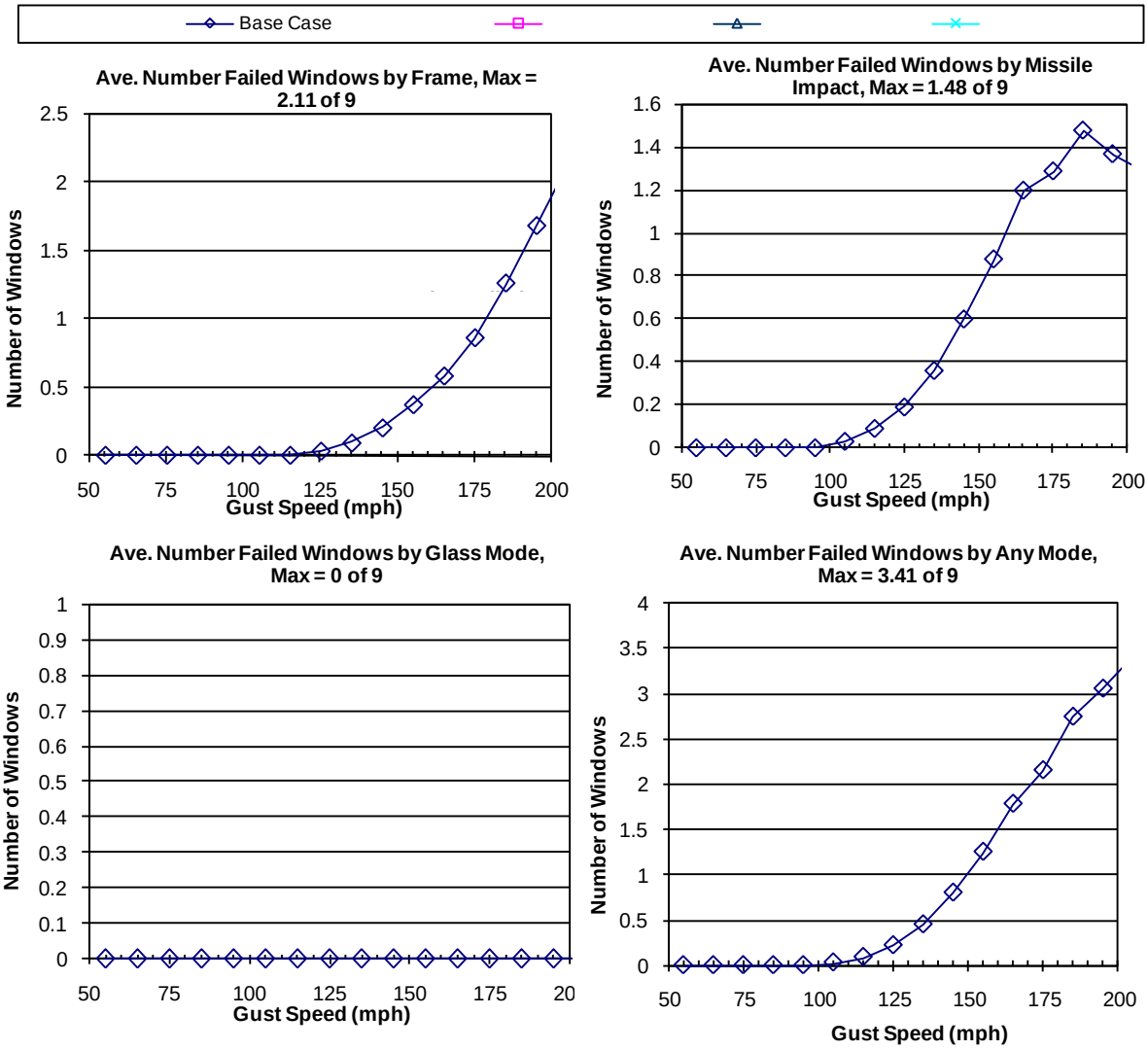




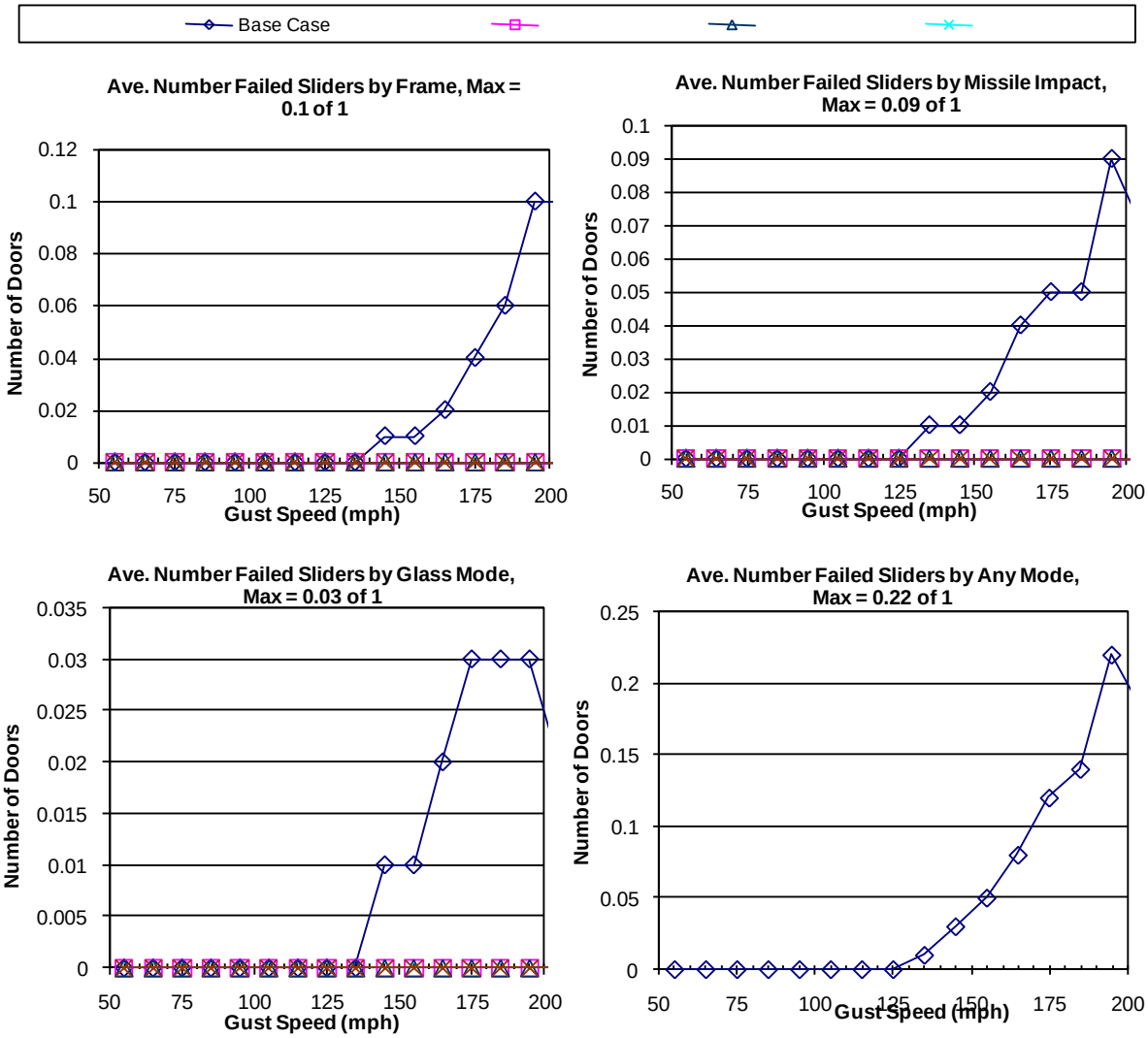
Miscellaneous Damage Measures



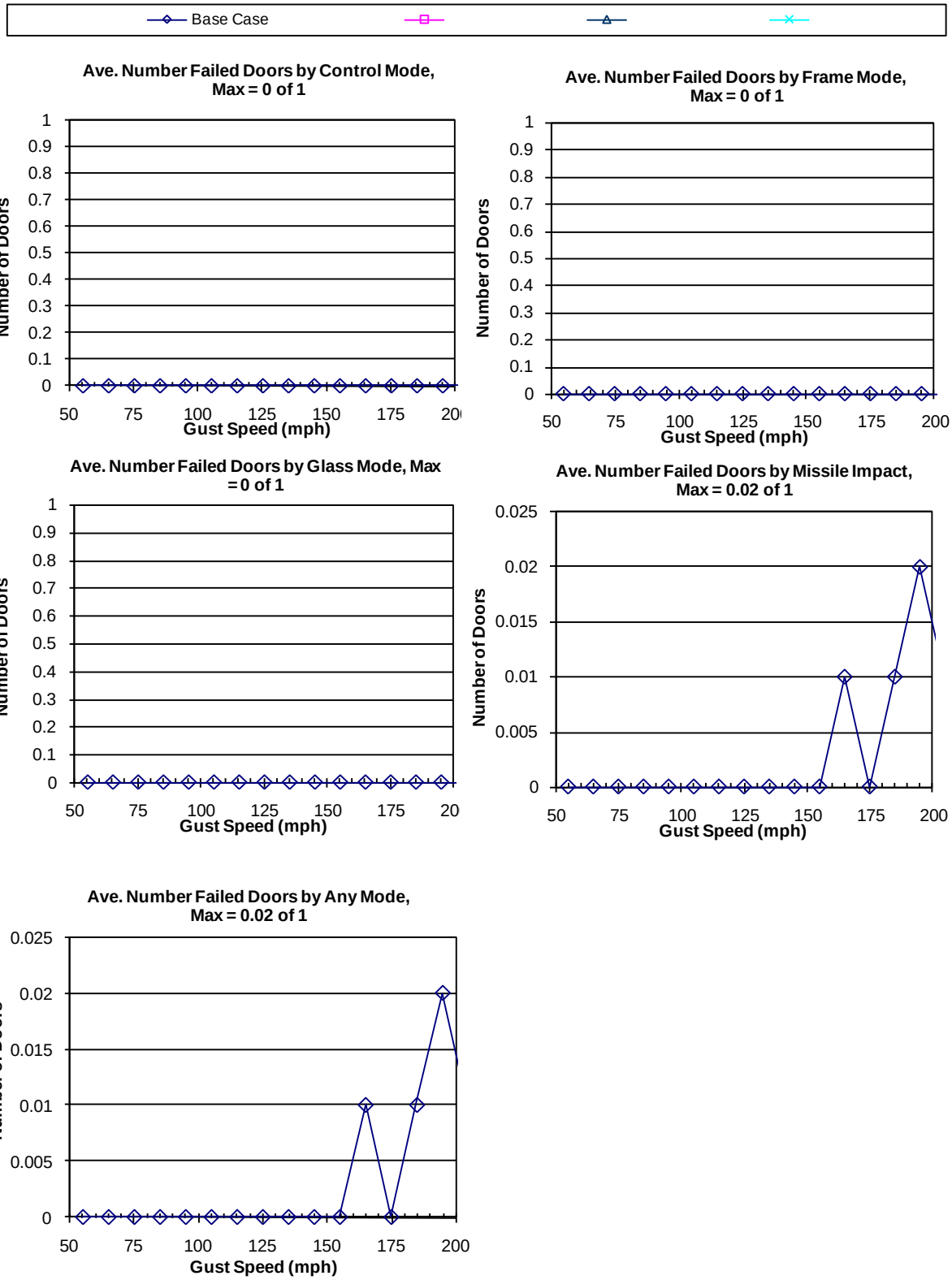
General Fenestration Damage



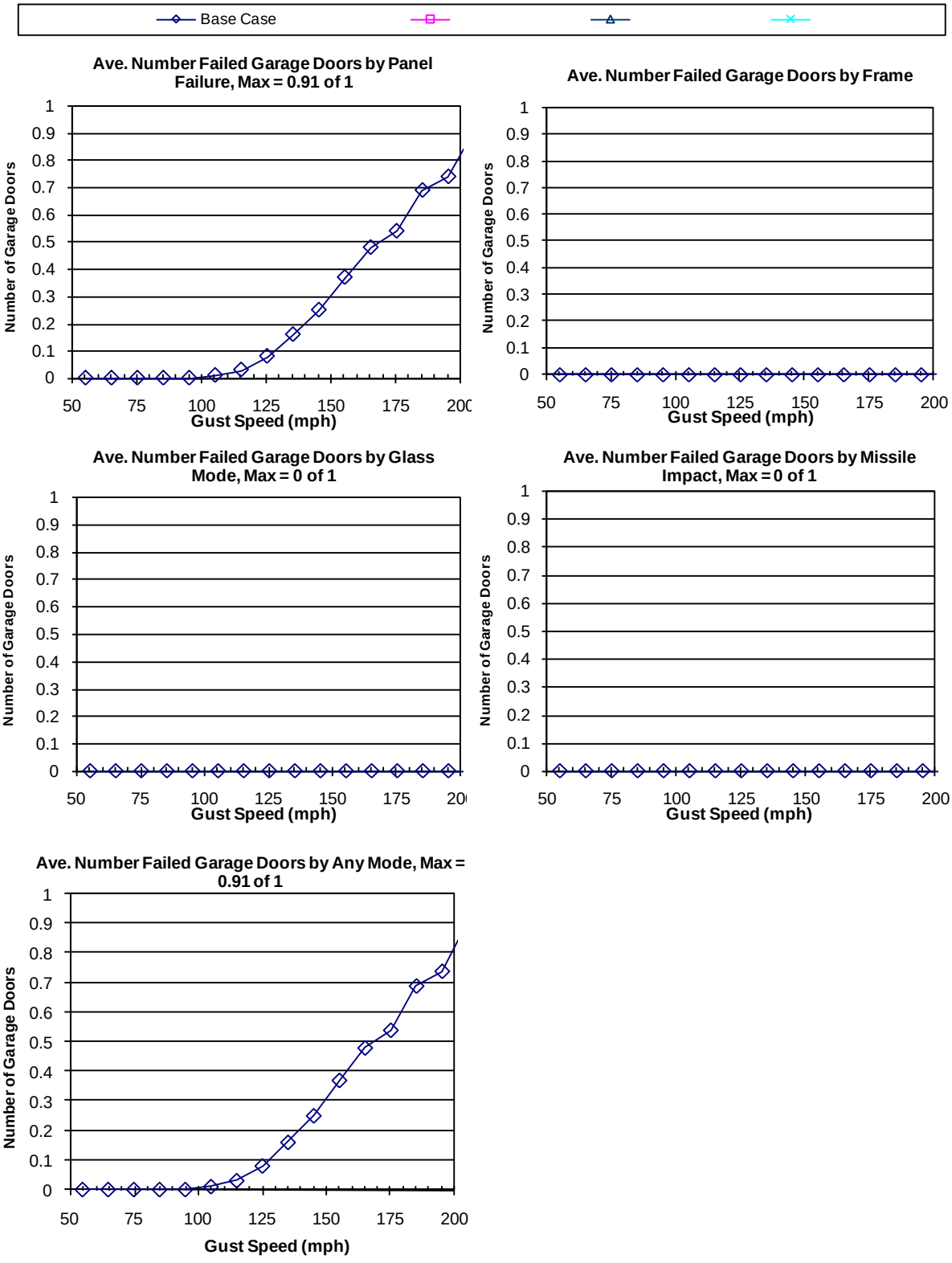
Window Damage



Slider Damage

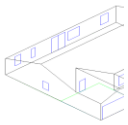

Base Case
Ave. Number Failed Doors by Control Mode, Max = 0 of 1
Ave. Number Failed Doors by Frame Mode, Max = 0 of 1
Ave. Number Failed Doors by Glass Mode, Max = 0 of 1
Ave. Number Failed Doors by Missile Impact, Max = 0.02 of 1
Ave. Number Failed Doors by Any Mode, Max = 0.02 of 1
Number of Doors
Gust Speed (mph)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.005
0.01
0.015
0.02
0.025
50
75
100
125
150
175
200

Door Damage



Garage Door Damage

HurReport - Single Family Residential



Building Description

Year: 2008

Stories: 1

		Resistance
Primary Roof Shape:	Gable	NA
Roof Cover: (ft-lbs)	Curved Tiles	38.5
SWR:	No	
Roof/Wall (lbs) Connection:	One-side Wrap	1200
Roof Deck:	Plywood	181.9
Roof Deck (psf) Attachment:	8d/6.00/6.00/4.00	
Wall (psf) Construction:		/

Type	*Plan*	*Roof*	*Wall*	*Fen*	*Glazing*
Area (sf)	2406	2600	2218	394	244
Percent	NA	NA	NA	18%	11%

Protection Level	***Area*** *(sf)*	***Percent ****
350 ft-lb @5%	244	11%

* percent of wall area for fens and percent of roof area for skylights.

Fen:	*Windows*	*Doors*	*Sliders*	*Garage*	*Skylights*
Cnt:	9	1	1	1	0

Program Parameters

Hurdam Directories:

Base: \runs

Program: \Programs\

Loss Directories:

Program: \Programs

Version:

HURSIM: HURLOSS:

HURDAM: MitCost: 2.6

RESCOMLOSS: 19 HurReport: 1.2

Wind Climate

Num of Year Sim: 500,000

Weighted: Yes

Sim File: \WindClimateData\SIMW00013.dat

			Mean		
Type	*Min*	*Max*	Azmth	*Sim*	*v^2*
Missile: R	1.00	1.00	1.00	1.00	1.00
Missile: C	0.00	0.00	0.00	0.00	0.00
Terrain:	0.35	0.35	0.35	0.35	0.35

Num Sim Per Storm: 30

100 Yr Wind Speed: 121 mph

250 Yr Wind Speed: 131 mph

1000 Yr Wind Speed: 147 mph

Annual Occ. Rate:

Latitude (deg): 27.0100

Longitude (deg): 82.3700

Orientation:

Inland Distance(km):

Location: Random

Economic Description

	Value	*Cap*
Building:	$165,206.00	1.25
Contents:	$82,603.00	1.00
ALE:	$33,041.20	1.00
Deductible:	0/3304/8260	

Cap Cont Cov: 0.5

Cap ALE Cov: 0.2

OHP: 1.2

R&R: 1.25

Global Results: Base Case

Average Damage State:

Ground Up AAL:

Ground Up Loss Cost:

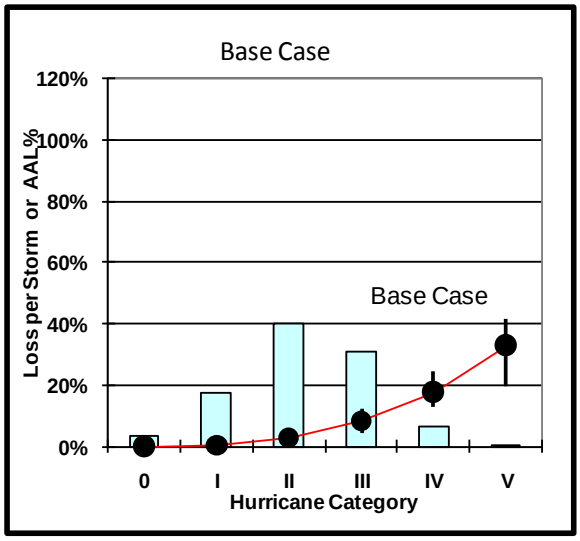
PML 100 yr:

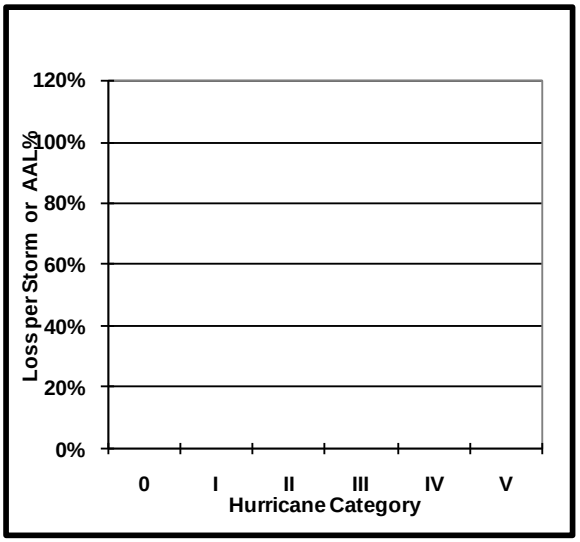
PML 250 yr:

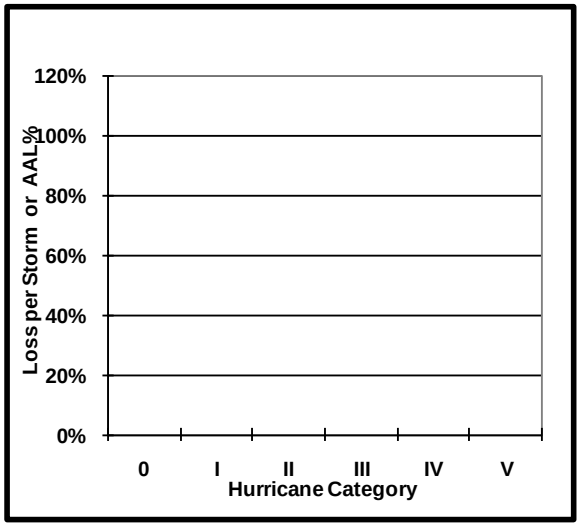
PML 1000 yr:

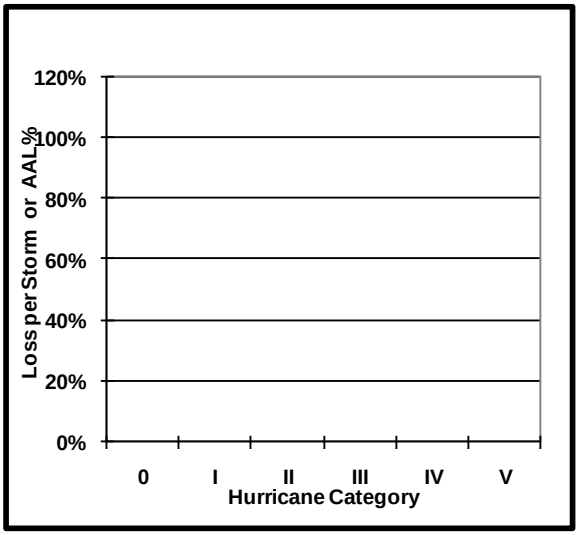
Vr: **Dflt** Tfact Roof: **Dflt** Tfact Fen Positive: **Dflt** Tfact Fen Negative: **Dflt**

LOSS CURVES FOR EACH PACKAGE - ONLY BASE CASE SHOWN





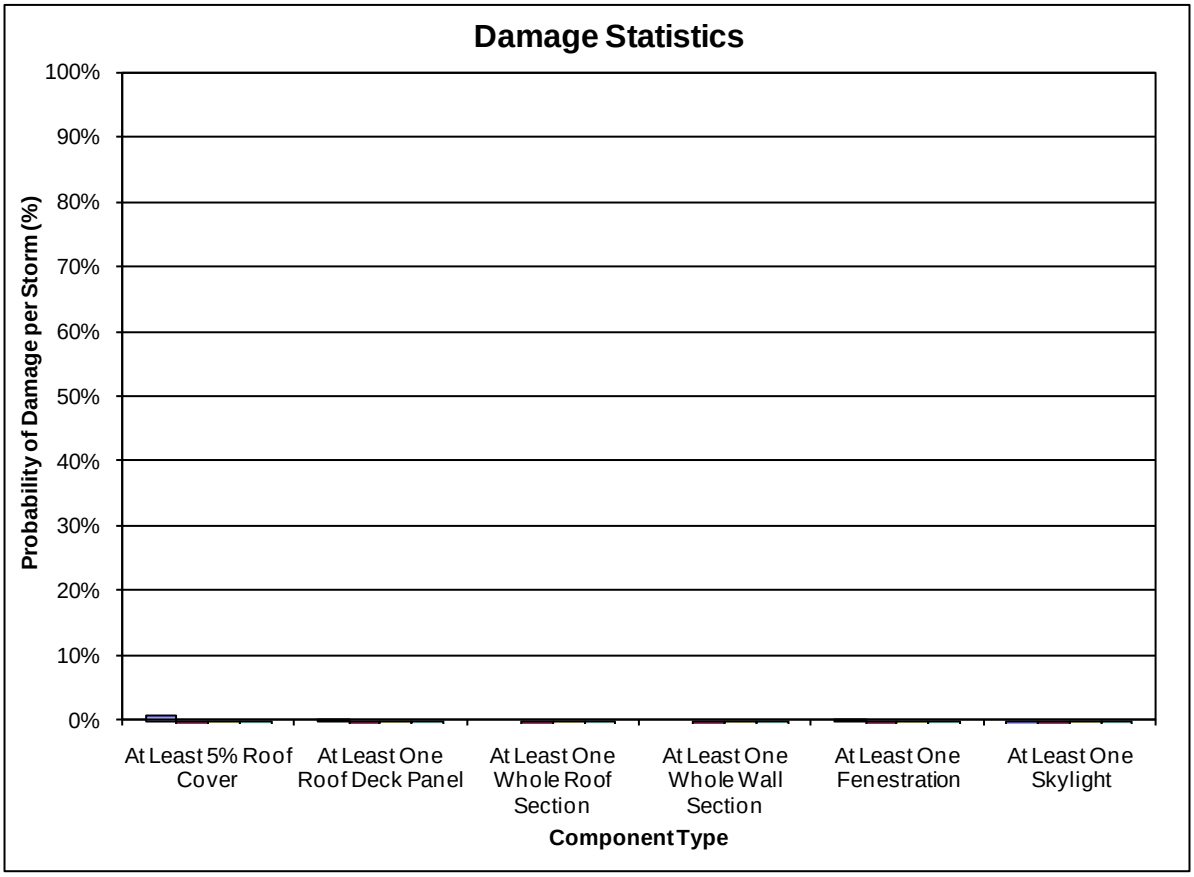


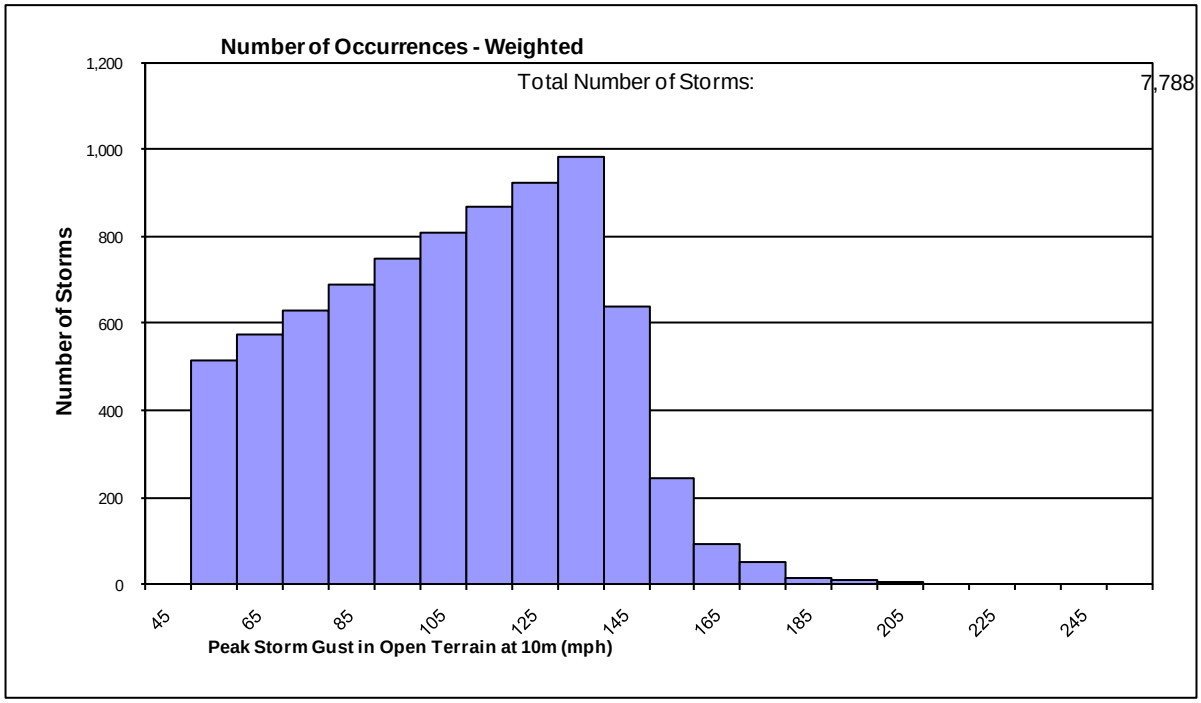


Building Characteristic	Resistances and Total Shutter Area			
	Base Case	Case 1	Case 2	Case 3
Roof Cover(ft-lbs)	38.500			
Roof Deck(psf)	181.900			
Secondary Water Resistance	No			
Roof/Wall Connection(lbs)	1,200.0			
Total Shutter Area / % of Wall Area	244 sqf / 0.11%			

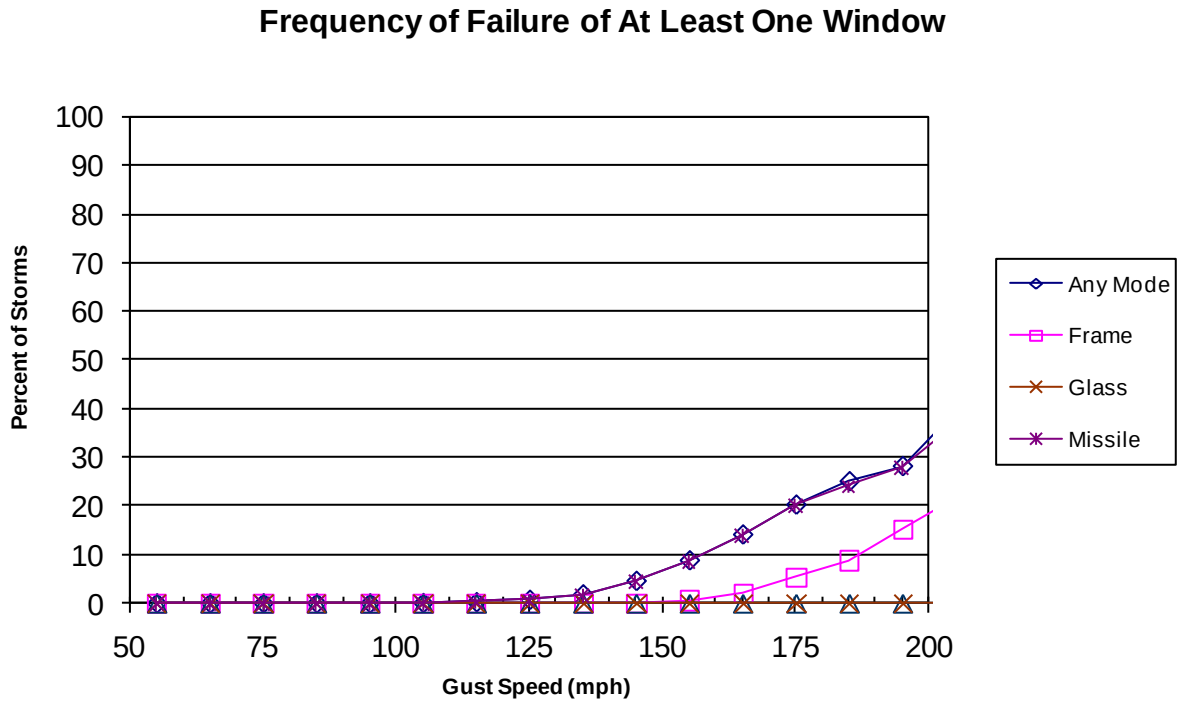
Global Results	Base Case	Case 1	Case 2	Case 3
Average Damage State	0.000			
Ground Up AAL	$0.00			
Ground Up Lost Cost	$0.00			
PML 100yr	$0.00			
PML 250yr	$0.00			
PML 1000yr	$0.00			

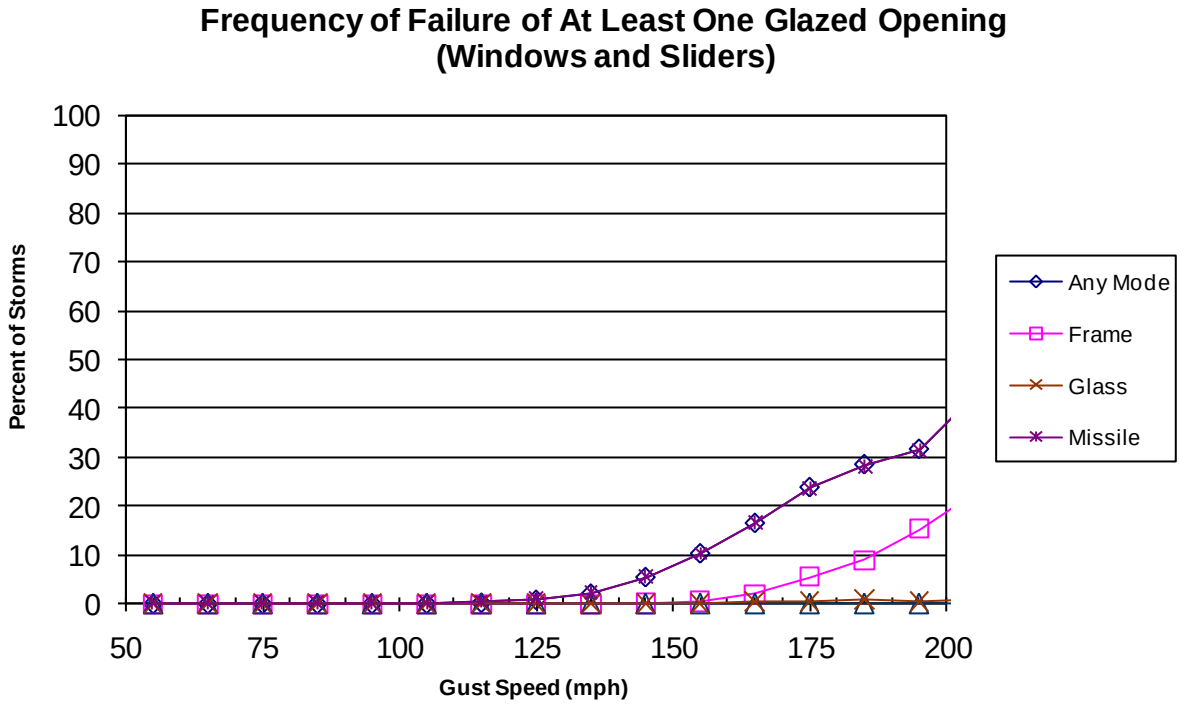
Cat.	Number of Storms
0	95,382
I	24,519
II	8,582
III	2,303
IV	232
V	11
Total	131,029



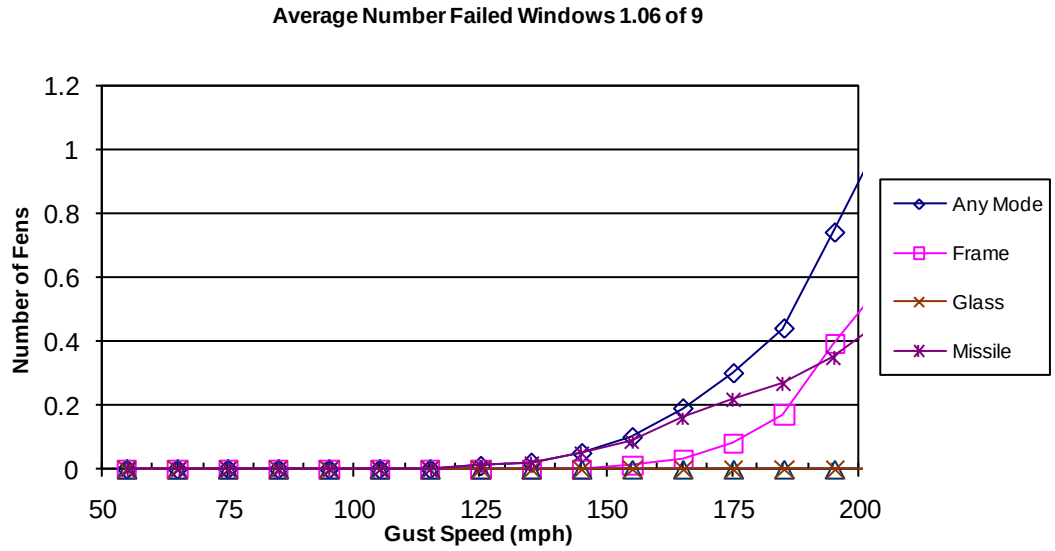


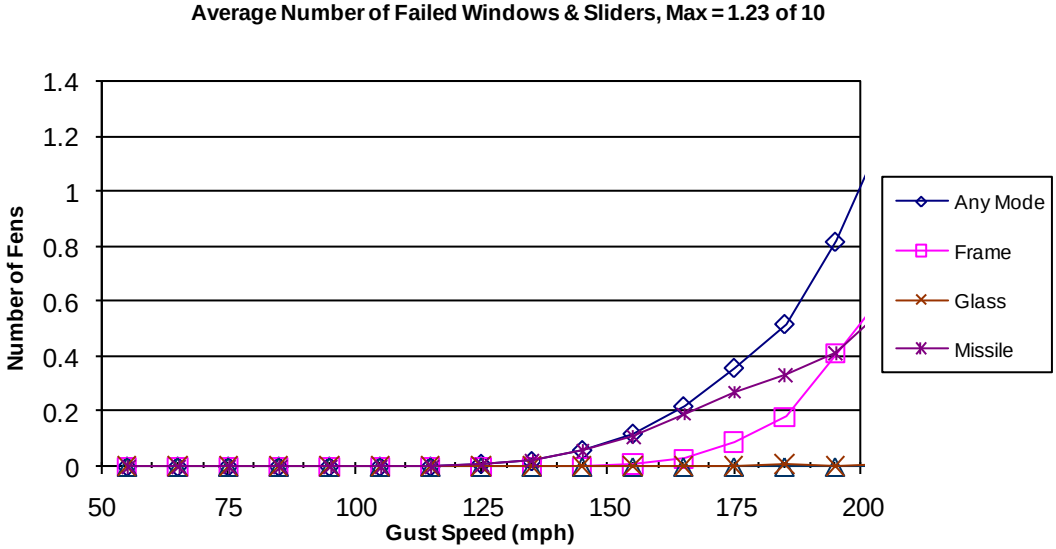
Damage Stats and Number of Storms



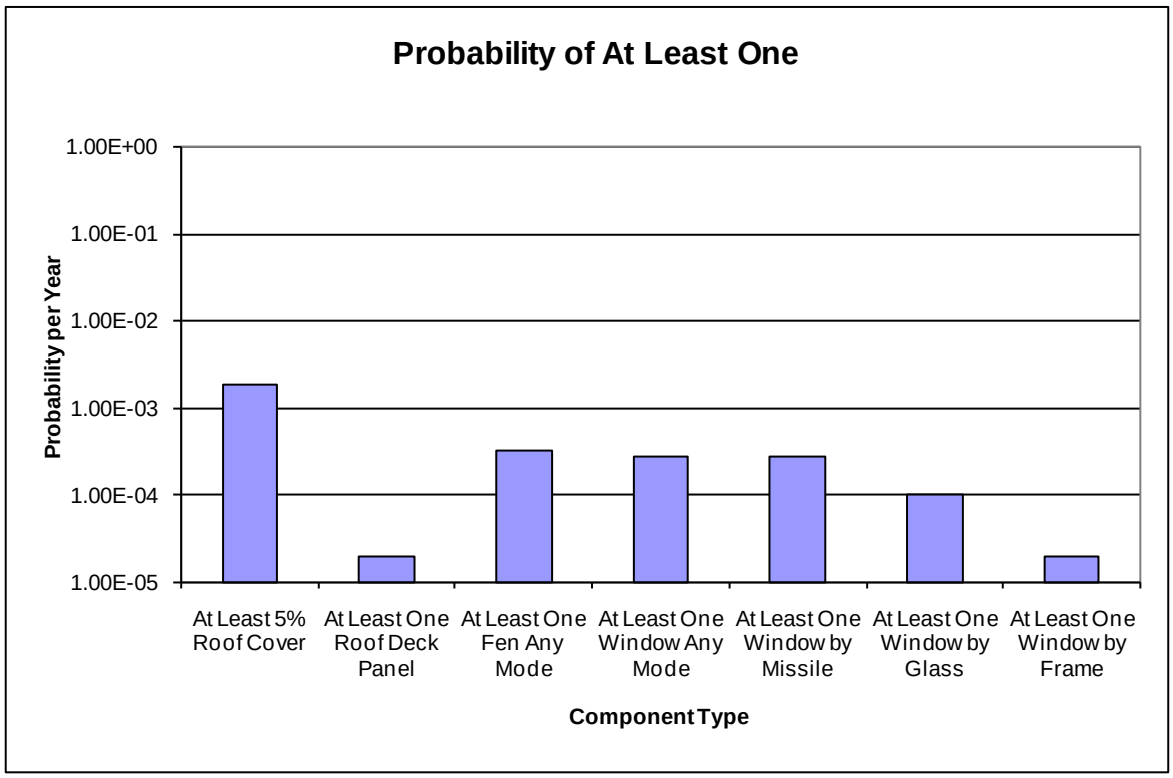


Frequency of Fenestration Failure

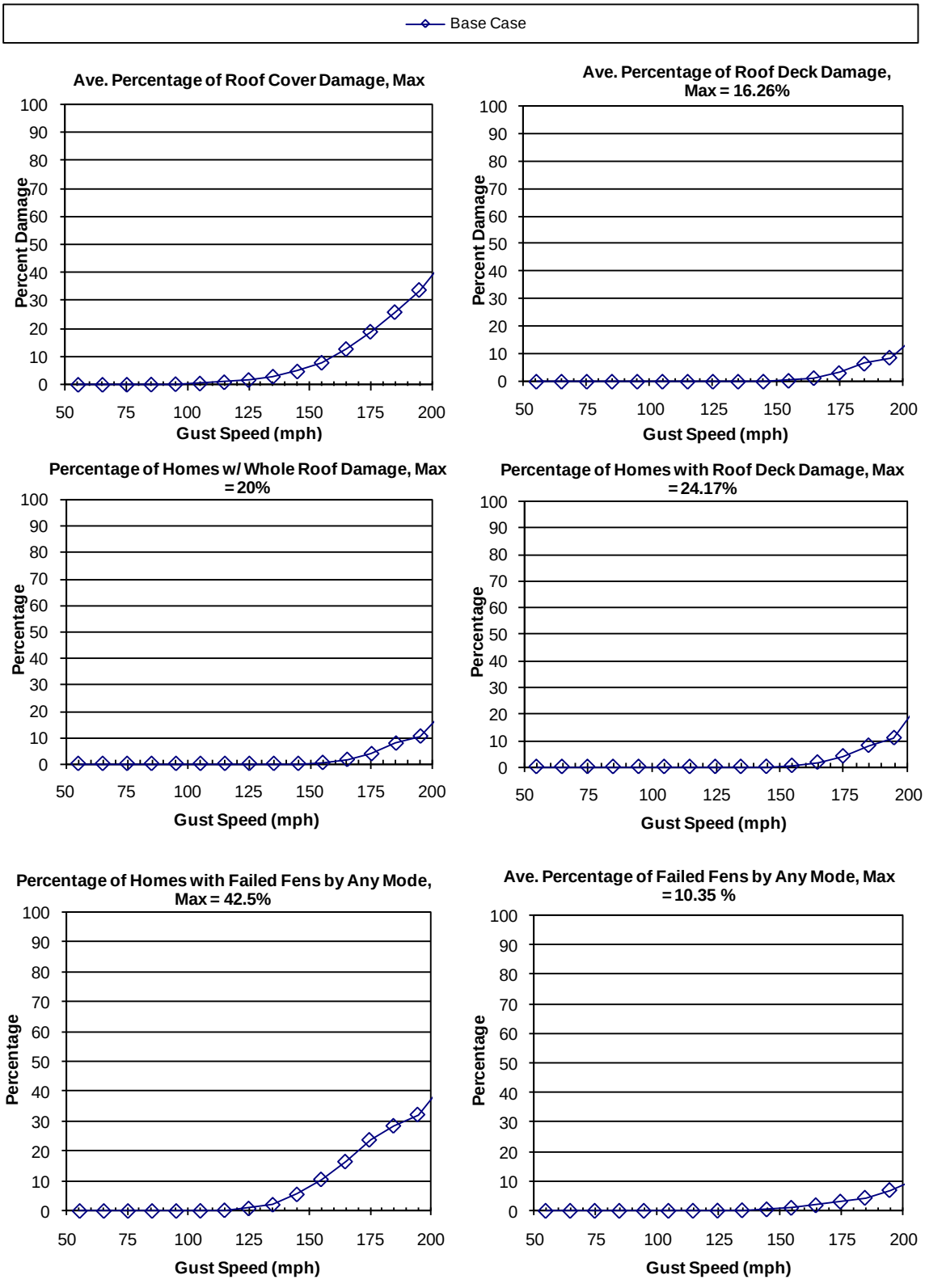




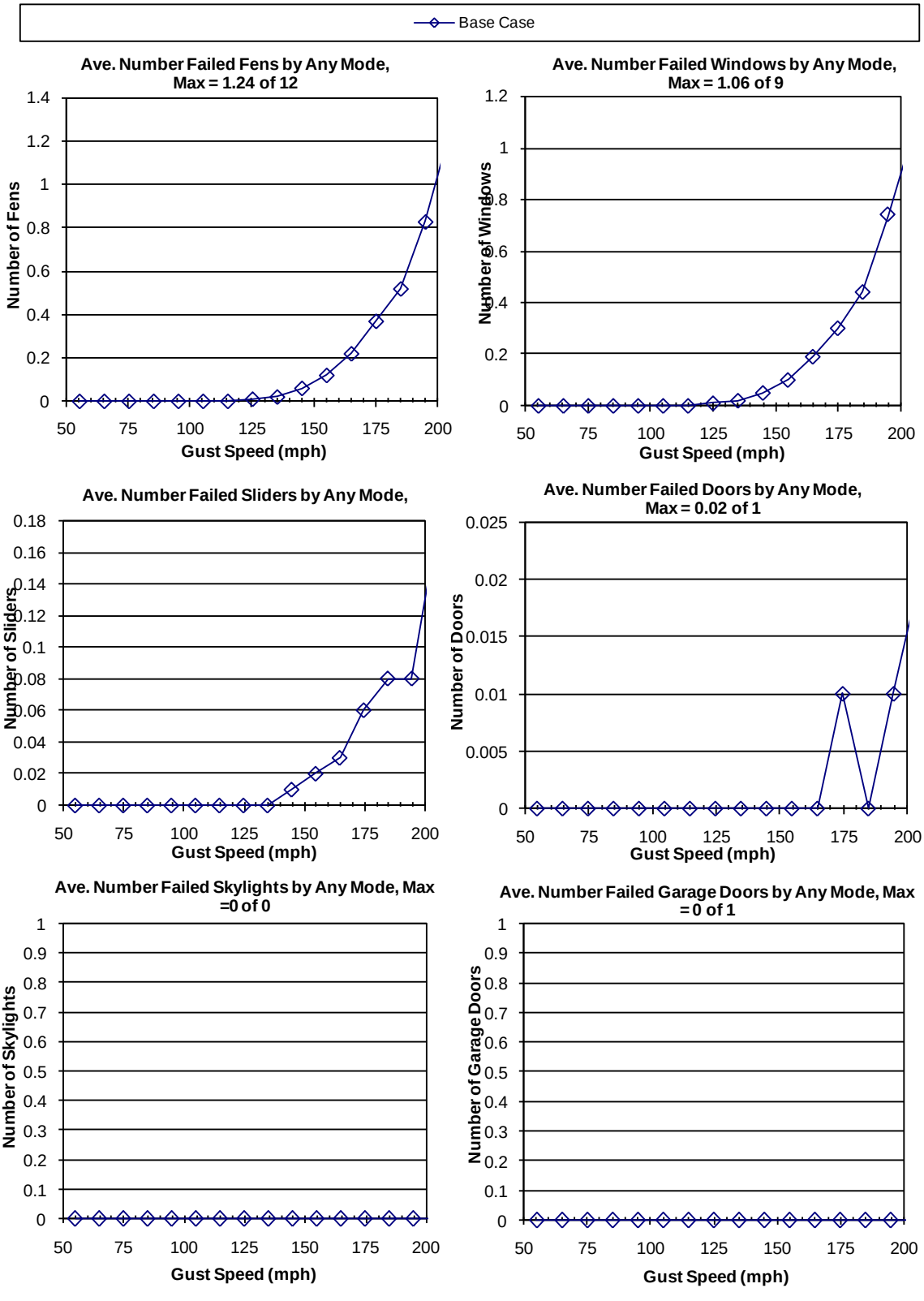
Average Number of Fenestration Failures



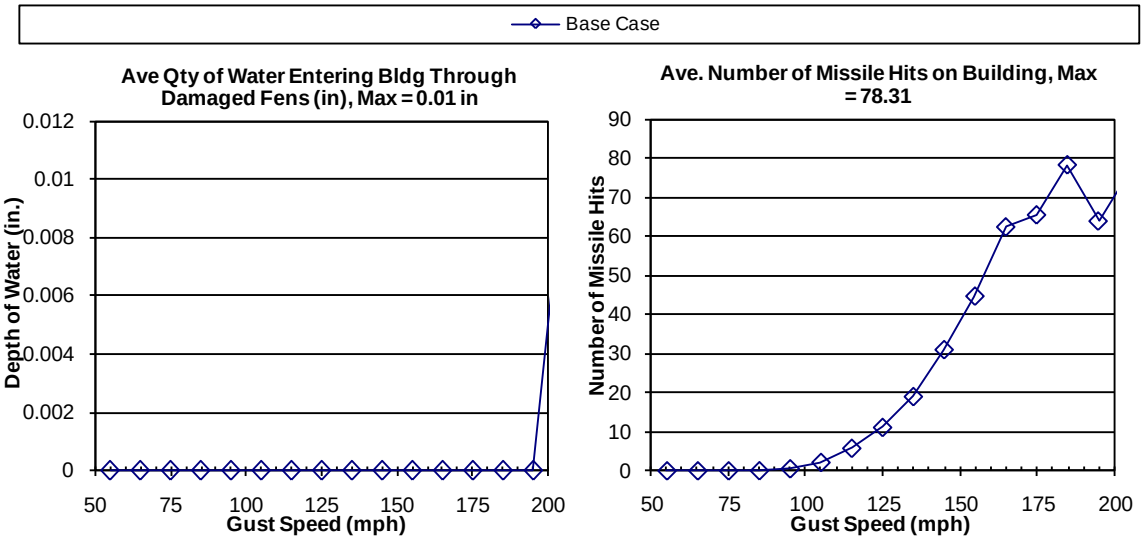
Probability of "At Least One" Damage

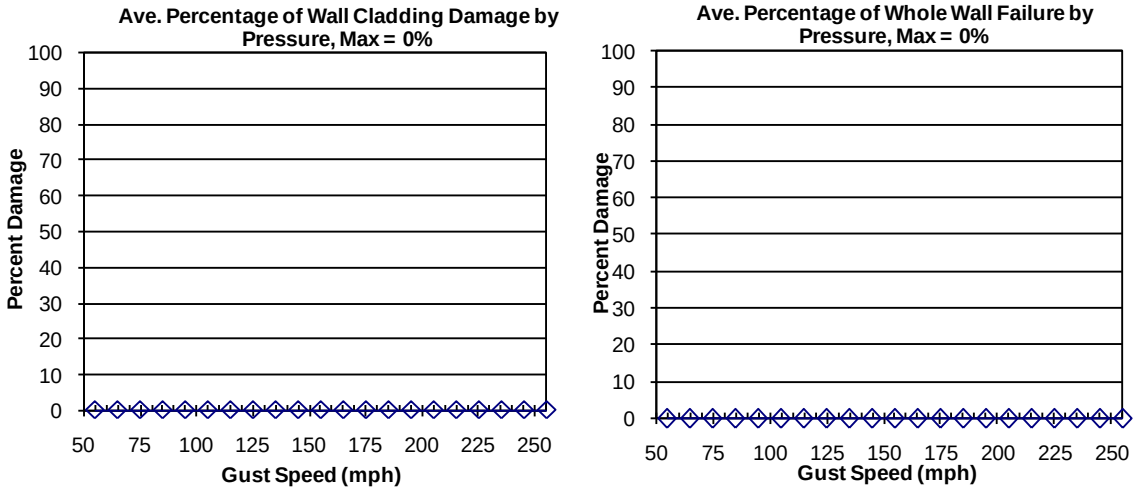

Base Case
Ave. Percentage of Roof Cover Damage, Max
Percent Damage
Gust Speed (mph)
Ave. Percentage of Roof Deck Damage, Max = 16.26%
Percent Damage
Gust Speed (mph)
Percentage of Homes w/ Whole Roof Damage, Max = 20%
Percentage
Gust Speed (mph)
Percentage of Homes with Roof Deck Damage, Max = 24.17%
Percentage
Gust Speed (mph)
Percentage of Homes with Failed Fens by Any Mode, Max = 42.5%
Percentage
Gust Speed (mph)
Ave. Percentage of Failed Fens by Any Mode, Max = 10.35 %
Percentage
Gust Speed (mph)

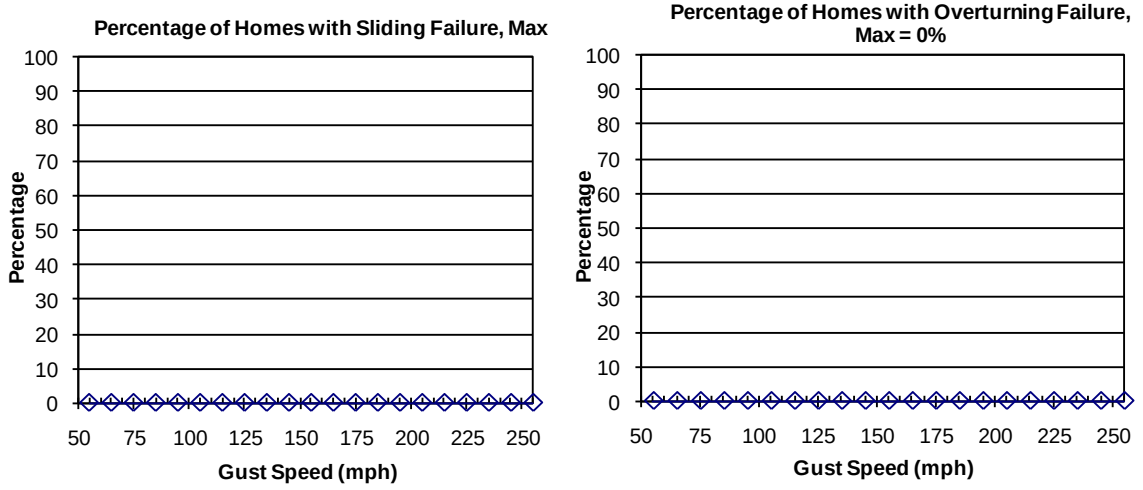
Roof Damage



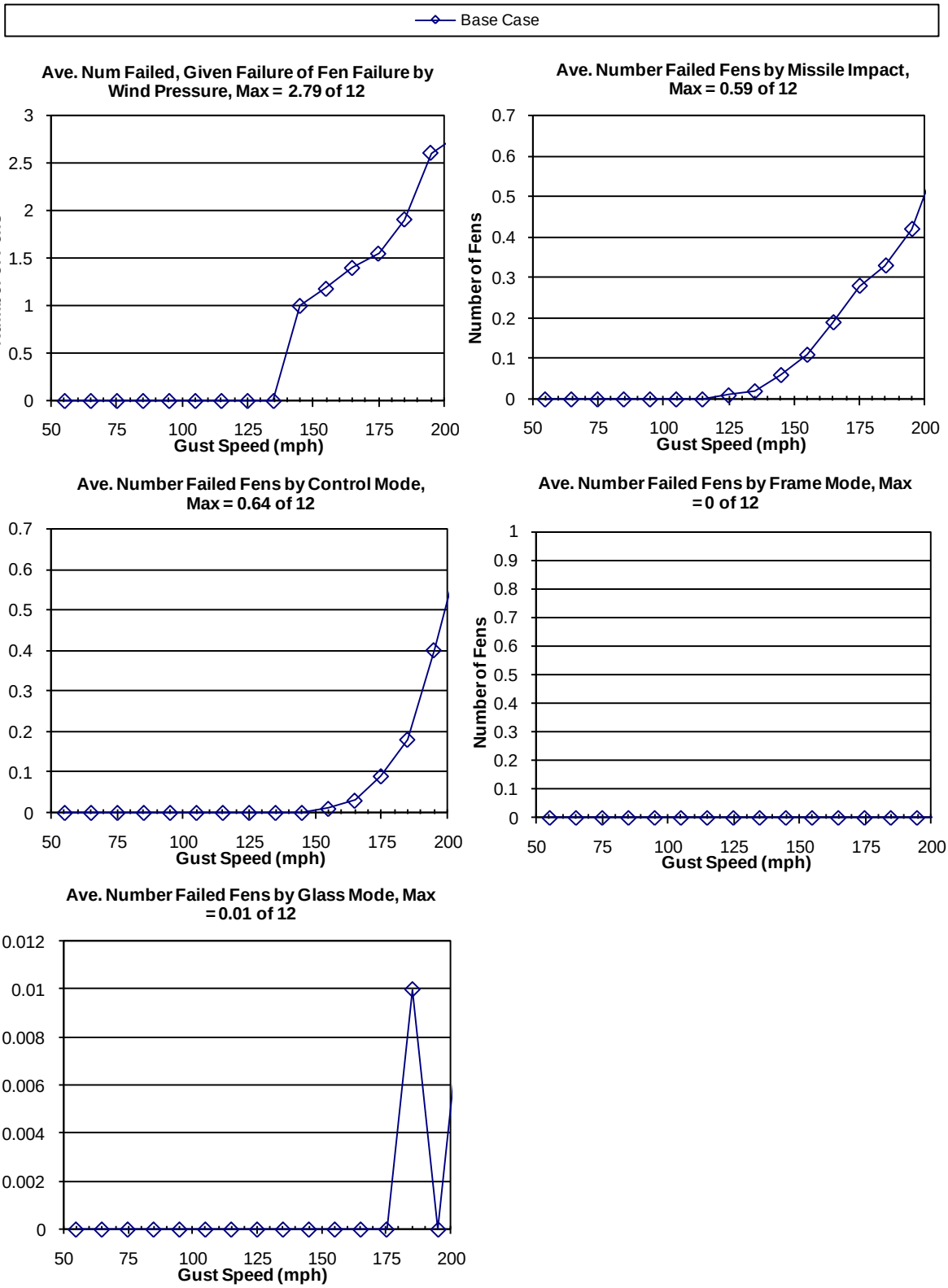
Fenestration Damage



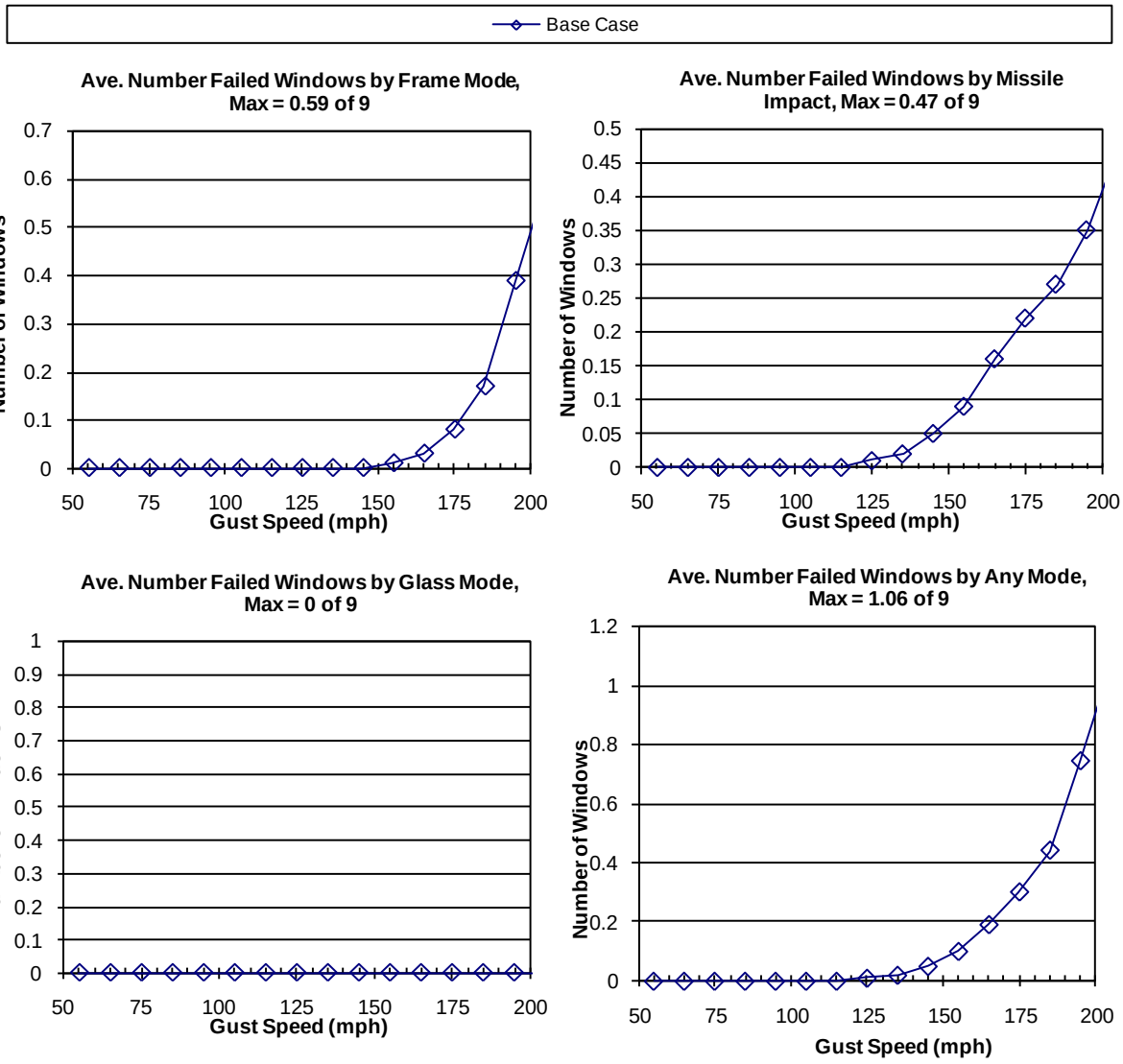




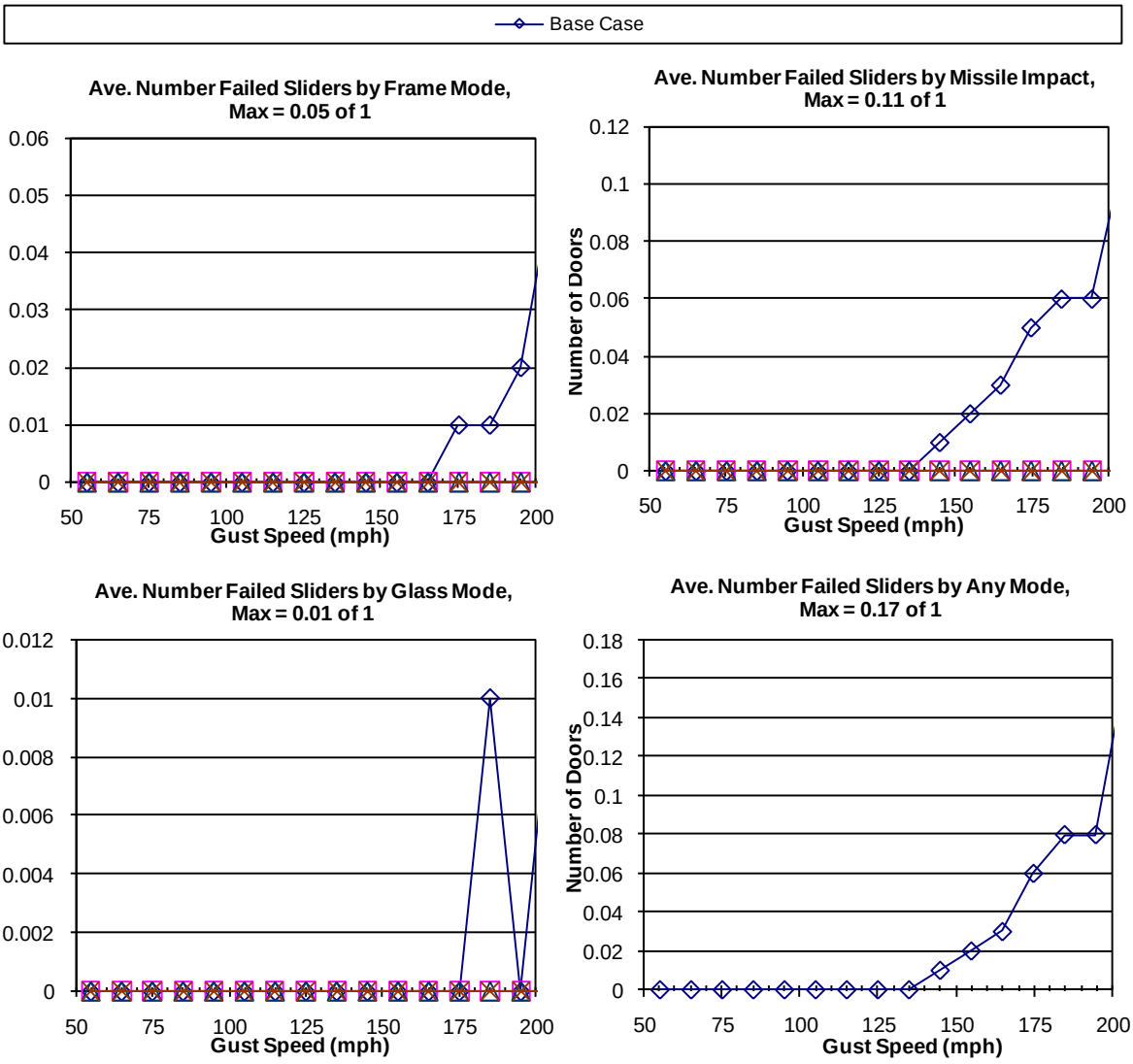
Miscellaneous Damage



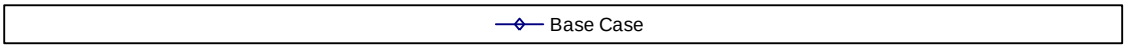
General Fenestration Damage

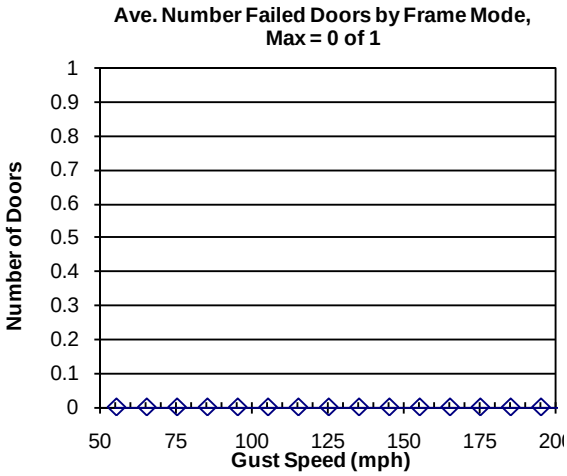


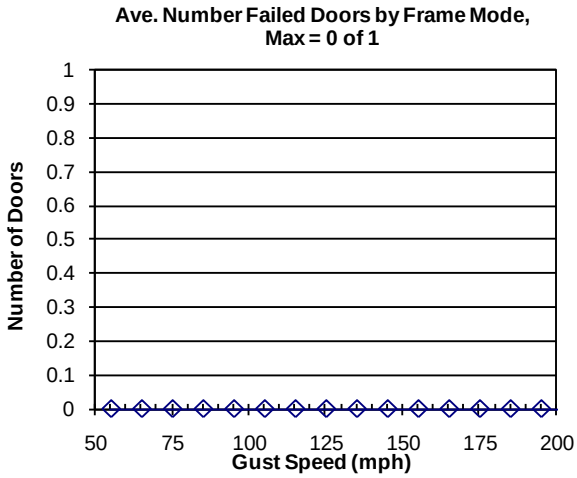
Window Damage

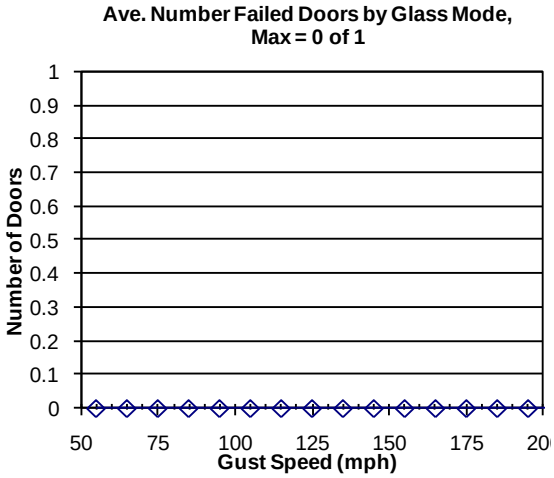


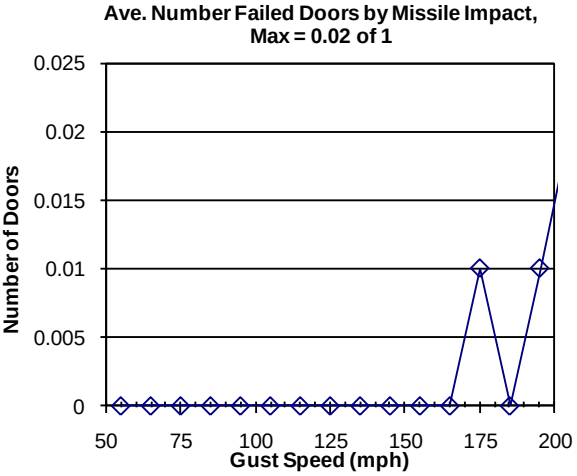
Slider Damage

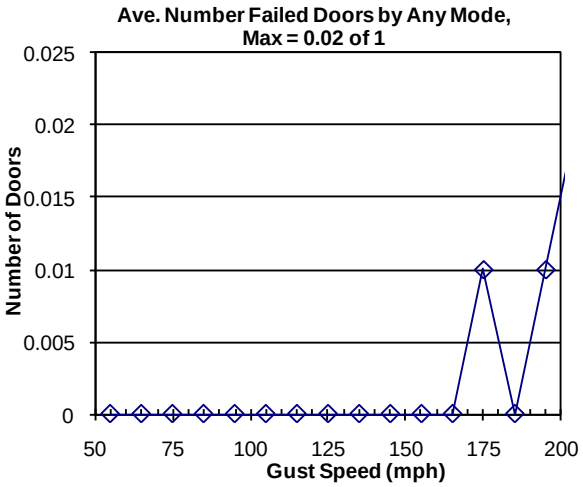

Base Case


Ave. Number Failed Doors by Frame Mode,
Max = 0 of 1
Number of Doors
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
75
100
125
150
175
Gust Speed (mph)


Ave. Number Failed Doors by Frame Mode,
Max = 0 of 1
Number of Doors
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
75
100
125
150
175
200
Gust Speed (mph)


Ave. Number Failed Doors by Glass Mode,
Max = 0 of 1
Number of Doors
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
75
100
125
150
175
Gust Speed (mph)


Ave. Number Failed Doors by Missile Impact,
Max = 0.02 of 1
Number of Doors
0.025
0.02
0.015
0.01
0.005
0
50
75
100
125
150
175
200
Gust Speed (mph)


Ave. Number Failed Doors by Any Mode,
Max = 0.02 of 1
Number of Doors
0.025
0.02
0.015
0.01
0.005
0
50
75
100
125
150
175
200
Gust Speed (mph)

Door Damage